TRANSACTIONS OF THE

American Foundrymen's Association

Proceedings of the

Thirtieth Annual Meeting

DETROIT, MICHIGAN

September 27 to October 1, 1926

VOLUME XXXIV

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Summary of the Proceedings of the Thirtieth Annual Meeting

Detroit, Mich., Sept. 27 to Oct. 1, 1926

The thirtieth annual meeting of the American Foundrymen's Association and twentieth exhibit of foundry equipment was held at the Michigan State Fairgrounds, Detroit, Mich., the exhibit opening Sept. 25, and the technical meetings beginning on Sept. 27, the convention, as a whole, closing on Friday, October 1. This thirtieth annual meeting was of exceptional importance for it was made the occasion for the holding of the Second International Foundrymen's Congress.

Surpassing all previous meetings, with a registration of 5,600 men, 469 ladies and a total of more than 150 overseas foundrymen representing twelve foreign countries, the meeting represents the high point in all respects of A. F. A. conventions.

With twenty-four technical sessions at which were presented fifty-seven papers and numerous committee reports, including eight papers by overseas foundrymen, the technical program was exceptional in adding research and practical data to the accumulated foundry knowledge. Of the technical sessions three were joint meetings with the Institute of Metals Division of the A. I. M. E., which held its fall meeting at this time.

The technical papers presented were divided as follows:

Non-ferrous, Foundry and Metallurgy	13
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Apprentice training was discussed at a session at which informal reports were presented. In connection with this session there was held an apprentice molding contest, with castings entered which were the winners of local contests held by four local foundrymen's organizations. The report of this contest will be found under the minutes of the business session.

Malleable foundry shop topics and non-ferrous foundry problems were discussed at two round table meetings.

Two informal sessions in foreign languages were held, The Franco-Belgian session having as chairman Robert Ronceray and the German session having as chairman Dr. Richard Moldenke. A detailed summary of the convention sessions follows:

Session No. 1—Opening Meeting
Monday, Sept. 27, 1:30 p. m.

President A. B. Root presided at this meeting which was held for the purpose of officially welcoming the overseas guests to the Second International Foundrymen's Congress.

After delivering his address of welcome, President Root introduced R. Crawford, President of the Detroit Foundrymen's Association, who, on behalf of his association, welcomed the members of the A. F. A. and their guests to Detroit.

Vice-President S. W. Utley of the A. F. A. was then introduced and he presented H. J. Campbell who, as the representative of the governor of Michigan, delivered an address of welcome. Following Mr. Campbell's address, President Root introduced the official representatives of the overseas foundry organizations. These were:

Paul Ropsy, President, Association Technique de Fonderie de Belgique.

E. V. Ronceray, Vice-President, Association Technique de Fonderie de France.

Dr. Ing. Geilenkirchen, Managing Director of the Verein Deutscher Eisengiesserein.

John Cameron, Past President, The Institute of British Foundrymen.

Carlo Vanzetti, Vice-President, Italian Foundrymen's Association.

T. J. Brons, representative, Cooperative Society of Dutch Iron and Steel Founders.

Sixten Nilsson, representative, Swedish Foundrymen's Association.

Norden Grindal, representative, Norwegian Foundrymen's Association.

Session No. 2—Aluminum and Aluminum-Alloys
Joint Session A. F. A. and Institute of Metals Division, A. I. M. E.
Monday, Sept. 27, 3:00 p. m.

G. H. Clamer, past president A. F. A., and P. D. Merica, Chairman Institute of Metals Division, jointly presiding.

Papers read were as follows:

CONSTITUTION OF ALUMINUM-ZINC-TIN ALLOYS AND ALUMINUM-ZINC-CADMIUM ALLOYS, by Dr. V. Jares, Technical School, Prague. This was the official contribution of the Czecho-Slovakian Foundry Association. The paper was presented by E. V. Ronceray.

ALUMINUM-ALLOY PERMANENT MOLD CASTINGS, by Dr. R. J. Anderson, Cincinnati, Ohio. In the absence of the author, this paper was presented by S. Tour.

ALUMINUM CASTINGS OF HIGH STRENGTH, by R. S. Archer and Zay Jeffries, Aluminum Co. of America, Cleveland, Ohio. The paper was presented by Mr. Archer.

EQUILIBRIUM RELATIONS IN ALUMINUM-COPPER ALLOY OF HIGH PURITY, by E. H. Dix, Jr., and H. H. Richardson, Aluminum Co. of America, New Kensington, Pa. The paper was presented by Mr. Dix.

Session No. 3—Materials Handling
Monday, September 27, 3:00 p. m.

Past President Benj. D. Fuller, presiding.

The papers dealing with materials handling in the foundry were presented by their authors and were amplified by the use of lantern slides. The papers were:

MATERIALS HANDLING IN A FOUNDRY, by E. T. Bennington, Cleveland Crane and Engineering Co., Wickliffe, Ohio.

SAVING FOUNDRY MATERIALS HANDLING, by H. J. Payne, the Society for Electrical Development, New York City.

Session No. 4—Core Binders and Cores
Monday, Sept. 27, 3:00 p. m.

W. J. Kihn, presiding.

Papers read were as follows:

A STANDARD SAND FOR USE IN TESTING CORE BINDERS, by H. L. Campbell, University of Michigan, Ann Arbor, Mich. Read by the author.

SOME PROPERTIES OF CORE OILS, by C. A. Hansen, General Electric Co., Schenectady, N. Y. Read by the author.

METHODS FOR DETERMINING THE PROPERTIES OF CORES MADE WITH CEREAL BINDERS, by H. L. Campbell, University of Michigan, Ann Arbor, Mich. Read by the author.

Session No. 5—Steel Founding
Tuesday, Sept. 28, 10:00 a. m.

John Howe Hall presiding.

Papers read were as follows:

DEFECTS IN STEEL CASTINGS, by R. S. Munson, Atlantic Steel Castings Co., Chester, Pa., presented by the author.

DEFECTS IN STEEL CASTINGS, by J. M. Sampson, General Electric Co., Schenectady, N. Y., presented by the author.

STEEL CASTINGS, PAST, PRESENT AND FUTURE, by Major R. A. Bull, Electric Steel Founders' Research Group, Chicago, Ill., presented by the author.

Session No. 6—Temperature Determination in the Non-Ferrous Foundry—A Symposium
Joint Session of the A. F. A. and Institute of Metals
Tuesday, Sept. 28, 10:00 a. m.

N. K. B. Patch representing the A. F. A. and W. M. Corse representing the Institute of Metals Division presided.

Short papers on the subject of determining temperatures in both brass and aluminum foundries were read as follows:

PYROMETER CONTROL IN A BRASS FOUNDRY, by A. S. Hall, Thwing Instrument Co., Philadelphia, Pa.

THE USE OF PYROMETERS IN THE CASTING OF NON-FERROUS METALS, by R. D. Bean, Brown Instrument Co., Philadelphia, Pa.

A THERMOCOUPLE FOR LADLE TEMPERATURES OF BRASS, by A. A. Grubb, L. H. Marshall, and C. V. Nass, The Ohio Brass Co., Mansfield, Ohio.

VISUAL JUDGMENT OF NON-FERROUS METAL TEMPERATURES, by R. R. Clarke, General Electric Co., Erie, Pa.

TEMPERATURE CONTROL IN ALUMINUM FOUNDRIES, by K. Marsh, Aluminum Co. of America, New Kensington, Pa.

TEMPERATURE CONTROL IN THE BRASS FOUNDRY, by H. M. St. John, Detroit Lubricator Co., Detroit, Mich.

PYROMETRY OF MOLTEN BRASS, by W. F. Roeser and C. O. Fairchild, U. S. Bureau of Standards, Washington, D. C.

Session No. 7—Apprentice Training
Tuesday, Sept. 28, 10:00 a. m.

H. A. Frommelt presiding.

At this session only one formal prepared paper was read, but representatives of foundry groups conducting apprentice training were called upon to discuss their training methods. J. C. Wright, director of the Federal Board of Vocational Education, of Washington, addressed the meeting on apprentice training. Others called upon to discuss the subject were:

L. S. Harding, Associated Metal Industries of Massachusetts, Boston, Mass.

G. Hass, Director of Vocational Education, Harvey, Ill.

C. J. Freund, Apprentice Supervisor, Falk Corporation, Milwaukee, Wis.

The paper read was:

APPRENTICE TRAINING RESULTS SECURED BY A LECTURE COURSE AND SUPERVISION, by P. R. Ramp, Newport News Shipbuilding and Dry Docks Co., Newport News, Va.

Session No. 8—Round Table Discussion on Brass Foundry Topics
Tuesday, Sept. 28, 12:45 p. m.

N. K. B. Patch presiding.

The discussion of an informal nature was held following a luncheon gathering. No reports of this meeting were made, as the purpose was to permit every one to express their views freely.

Session No. 9—Permanent and Long-Life Molds
Tuesday, Sept. 28, 2:00 p. m.

Jesse L. Jones presiding.

Papers read were:

CENTRIFUGAL TUBE CASTING IN HOT MOLDS, by Leon Cammen, Associate Editor, The American Society of Mechanical Engineers, New York, N. Y.

NOTES ON THE DEVELOPMENT OF CENTRIFUGAL CASTING PROCESS IN GREAT BRITAIN AND EUROPE, by J. E. Hurst, Newton-Chambers and Co., Sheffield, England. In the absence of the author this paper was presented by John Cameron.

DURABLE MOLDS, by James A. Murphy, Hamilton, Ohio.

A PERMANENT MOLD PROCESS, by H. A. Schwartz, Cleveland, Ohio.

SOME CONSIDERATION OF METAL FOR HEAVY IRON CASTINGS IN PERMANENT MOLDS, by H. P. Kimber and S. M. Udale, The Holley Carburetor Co., Detroit, Mich.

PERMANENT AND LONG LIFE MOLDS, by Dr. Richard Moldenke, Watchung, N. J.

Session No. 10—Cupola and Gray Iron Shop Practice
Tuesday, Sept. 28, 2:00 p. m.

J. W. Bolton presiding.

Papers read were as follows:

MELTING ALL STEEL HEATS IN THE CUPOLA, by T. F. Jennings, Utah Copper Company, Garfield, Utah.

A STUDY OF IRON MELTED IN THE CUPOLA, by R. E. Wendt and J. P. Walsted, Purdue University, Lafayette, Ind.

Chaplets in Heavy Iron Castings, by Ivan Lamoureux, Liege, Belgium, presented on behalf of the Association Technique de Fonderie de Belgique.

A Study of Gating Iron Castings, by H. W. Dietert, U. S. Radiator Corp., Detroit, Mich.

Session No. 11—Franco-Belgian Language Conference
Tuesday, Sept. 28, 2:00 p. m.

Robert Ronceray presiding:

This session was arranged to give those of our guests speaking French an opportunity to gather together and informally discuss any subject that those in attendance desired to bring up. No stenographic report was kept.

Session No. 12—Steel Foundry Metallurgy
Wednesday, Sept. 29, 10:00 a. m.

Chairman A. H. Jameson.

The following papers and reports were read and discussed:

Some Physical Properties and Compositions of Cast Converter Steel, by C. M. Campbell, West Steel Casting Co., Cleveland, Ohio.

Open Hearth Slags, by W. C. Hamilton, American Steel Foundries, Indiana Harbor, Ind.

Manganese in Carbon Steel Castings, by John Howe Hall, Taylor-Wharton Iron and Steel Co., High Bridge, N. J.

Report of A. F. A. Representative on Joint Committee to Investigate Effect of Phosphorus and Sulphur in Steel.

Report of Committee on Steel Castings.

Following the report of Major R. A. Bull, as the A. F. A. representative on the Committee to Investigate the Effect of Phosphorus and Sulphur in Steel, a lengthy discussion took place, and the following resolution was presented, seconded and approved:

"That it is the sense of this meeting that the A. F. A. support the program of the Joint Committee to Investigate the

Effect of Phosphorus and Sulphur in Steel for the investigation of the effect of the phosphorus in steel castings, provided the investigation is confined to coupons." The resolution was referred to the A. F. A. Board of Directors for approval.

Session No. 13—Testing Cast Iron
Wednesday, Sept. 29, 10:00 a. m.

Chairman L. L. Anthes, Past President A. F. A.

Papers read and discussed were:

A SHEARING TEST FOR CAST IRON, by G. K. Elliott, presented by J. W. Bolton.

THE STRENGTH OF CAST IRON IN RELATION TO ITS THICKNESS, by W. H. Rother and V. M. Mazurie, Buffalo Foundry and Machine Co., Buffalo, N. Y. Presented by V. M. Mazurie.

SOME GRAY IRON PROBLEMS, by John Shaw, Brightside Foundry and Engineering Co., Sheffield, England. This is the annual exchange paper of the Institute of British Foundrymen, and was presented by the author.

TESTING CAST IRON, by A. E. leThomas, Indret, France. This, one of two exchange papers offered on behalf of the Association Technique de Fonderie de France, in the absence of the author, was presented by E. V. Ronceray, vice-president of the French Foundry Technical Association.

At the beginning of this session, Chairman Anthes announced the recent death of Mr. George K. Elliott, the author of the first paper on the program. The session stood in silence for a moment in respect to Mr. Elliott's memory.

A resolution was passed that a message of condolence be sent to Mrs. G. K. Elliott, following which Mr. Elliott's contribution was read in full by J. W. Bolton.

Session No. 14—Malleable Cast Iron
Wednesday, Sept. 29, 10:00 a .m.

L. C. Wilson presided as chairman.

Papers read and discussed were as follows:

A STUDY OF MALLEABLE CAST IRON, by Dr. O. Quadrat and

J. Koritta, Prague, Czecho-Slovakia, presented on behalf of the Czecho-Slovakian Foundry Association, and in the absence of the author, read by W. R. Bean.

Resistance of Malleable Iron to Repeated Impact Stresses, by Enrique Touceda, Albany, N. Y.

What May Be Required of Malleable Cast Iron, by H. A. Schwartz, National Malleable and Steel Casting Co, Cleveland, Ohio.

Following the discussion of the paper by Mr. Schwartz, a motion was made, seconded and carried as follows:

"That the method of determination of the yield point of malleable iron be referred to the A. F. A. Committee on Malleable Iron, in cooperation with the proper committee of the American Society for Testing Materials."

Session No. 15—Institute of Metals Division
Wednesday, Sept. 29

Session No. 16—Foundry Costs
Wednesday, Sept. 29, 2:00 p. m.

Chairman A. E. Hageboeck:

Papers read were:

Need for Uniform Cost Accounting Systems, by E. W. McCullough, Department of Manufacture, U. S. Chamber of Commerce, Washington, D. C.

Foundry Cost Accounting, by R. E. Belt, American Malleable Castings Association, Cleveland, Ohio.

Following the presentation of these two papers, there was a discussion as to the part the A. F. A. should take in establishing a uniform cost system for foundries. At this time the following resolution was offered, seconded and carried.

"*Resolved,* That the American Foundrymen's Association approve the recommendation of the Cost Committee; that the American Foundrymen's Association develop a uniform cost system and

"*Second,* That when the system is produced and approved, it be recommended for the use of all members, including the various groups."

The motion was referred to the Board of Directors for approval.

Session No. 17—Foundry Refractories
Wednesday, Sept. 29, 2:00 p. m.

Chairman L. C. Hewitt of the Joint Committee on Foundry Refractories, and Chairman C. N. Ring of the A. F. A. Committee on Refractories, presiding.

Committees of the Joint Committee reported as follows:

L. C. Hewitt reported as chairman of the Joint Committee.

James R. Allan reported as chairman of the sub-committee on Survey of Refractories of the Malleable Industry.

C. N. Ring reported as chairman of the sub-committee on Survey of Refractories of the Steel Foundry Industry.

H. M. St. John reported as chairman of the sub-committee on Survey of Refractories of the Non-Ferrous Foundry Industry.

H. R. Colwell presented on behalf of Chairman W. J. Corbett, the report of the sub-committee on Standardization and Simplification.

Session No. 18—Foundry Sand Control
Thursday, Sept. 30, 10:00 a. m.

R. F. Harrington presided.

Committee reports and papers read were as follows:

Report of Chairman of the Joint Committee on Molding Sand Research was read by W. M. Saunders.

Report of the Sub-Committee on Tests was read by Dr. H. Ries.

H. Frechette read a supplementary report to that of the sub-committee on tests detailing work on refractoriness of sands as carried out by the Canadian Department of Mines.

W. M. Saunders presided as Chairman, while R. F. Harrington read the report of the sub-committee on Conservation and Reclamation of Foundry Sands.

A. A. Grubb read the report of the sub-committee on grading.

Each of the reports were accepted for approval and forwarded to the Board of Directors for final acceptance.

The papers read were:

Some Practical and Technical Data Obtained From the Use of Clay Additions to Molding Sand Heaps, by R. F. Harrington, A. S. Wright and M. A. Hosmer, Hunt-Spiller Mfg. Corp., Boston. The paper was presented by R. F. Harrington, while W. M. Saunders temporarily acted as chairman.

Strength Testing of Foundry Sands, by T. C. Adams, Cornell University, Ithaca, N. Y. This paper was presented by title.

Sand Control in the Foundry, by H. W. Dietert, U. S. Radiator Corp., Detroit, Mich.

Session No. 20—Round Table Discussions on Malleable Foundry Topics

Thursday, Sept. 30, 12:30 p. m.

Chairman, F. L. Wolf.

The discussion of an informal nature was held immediately following a luncheon gathering. No record of the meeting was made, as the purpose was to permit everyone to express freely their views.

Session No. 21—Business Meeting

Thursday, Sept. 30, 1:30 p. m.

President A. B. Root presided as chairman.

President Root read the annual address of the president which is reproduced elsewhere in this volume. Secretary Hoyt read the report of the election of officers and directors which named the following as officers and directors:

For President to serve one year, S. W. Utley, Detroit, Mich.

For Vice-President to serve one year, S. T. Johnston, Chicago, Ill.

For directors to serve three years:

M. W. Henley, Syracuse, N. Y.
N. K. B. Patch, Buffalo, N. Y.
A. B. Root, Jr., Boston, Mass.
S. C. Vessy, Cleveland, Ohio
L. C. Wilson, West Allis, Wis.

It was duly moved and seconded that the secretary cast the unanimous ballot of the members present for the election of the officers and directors nominated by the Nominating Committee. The secretary cast the ballot and the chairman declared the aforenamed officers and directors elected, to take office on the date of the annual meeting of the Board of Directors. The newly elected officers and directors present were introduced. Past President, A. E. Howell, chairman of the Committee on Resolutions, submitted the following resolutions which were unanimously adopted:

Detroit has been the hospitable host of the most remarkable meeting in the history of the 30 years of the life of this Association. For the third time we meet in Detroit. The progress of Detroit—since our first meeting here in 1897—our second in 1910 to this our third, gives us a vivid impression of the strides of our own industry. Probably no other industry has contributed so much to the growth of Detroit—nor has Detroit promoted the growth of any other industry—to the extent it has that of the founding of metals.

Detroit was the wise choice for holding the second International Foundrymen's Congress—because Detroit exemplifies to our own people and to our overseas guests the marvels that exist today in modern methods of efficiency and vast production that were but a dream, inconceivable to the matter of fact mind—at the time our Association was formed in 1896.

The sincerity and warmth of the invitation of her representatives, also contributed to our decision to meet in Detroit.

Now our meeting draws to a close—we have partaken of Detroit's bountiful hospitality, extended with the most sincere cordiality—which seems to have grown in warmth with like proportions, as her material prosperity—therefore be it resolved

That we deeply appreciate the action of the Governor of the State of Michigan and the State Fair Board in granting the use of the buildings and grounds. We thank the Mayor of Detroit who magnanimously accorded to our industry the reason for the magical growth of the city. We are grateful to the local Detroit Committees (known to every one of us, but too numerous to mention in detail), of which Mr. Robert Crawford was general chairman.

To the Ladies' Committees, who so graciously gave the atmosphere of home and charm, we extend our felicitations and profound admiration.

We are indebted to all the Patron Industries who not only welcomed us to Detroit but to their plants, where every courtesy and attention was given each visitor in viewing and explaining the multifarious processes.

To the Press—to the Hotels—to all those individually and collectively who contributed of their time and substance—but more—of their evident heartfelt and kindly interest and good fellowship—we are profoundly appreciative and grateful.

Our own Officers and committees have been indefatigable and deserve our greatest praise.

President A. B. Root, Jr., has not only been engrossed in our Detroit Meeting and the very numerous preparations, culminating in this most successful convention, but in addition has acted as host to our Overseas Guests, whom he met in New York, where suitable arrangements were made for their reception, under the general chairmanship of Mr. V. E. Minich, assisted by local committees. We are grateful to the Chairman and Committees of each of the cities where our Overseas Guests have been received and entertained. We should especially thank Mr. H. Cole Estep, Chairman of International Relations, who has given without stint of his time and talents.

The Technical Program has been varied and extensive. To the authors and committee workers the Casting Industries of the world are indebted. To each of them we extend our sincere appreciation. To our Overseas contributors we particularly desire to express our gratitude.

The Exhibits have made a record in numbers, variety and quality. The American Foundrymen's Association feel deeply appreciative of the whole-hearted cooperation of the manufacturers, of the varied foundry appliances, machines, equipment and materials brought together to form that vast Exhibit. Back of all the great activities of our Association, made manifest in what you see and hear and read—are the thinkers—the dreamers—if you will, who make their dreams come true.

We refer to our Executive Organization—President A. B. Root, Jr.—Vice President S. Wells Utley (our new President-elect), members of the Executive Committee and the Board of Directors, who serve you with untiring zeal—with no reward save the gratitude of those who recognize and understand their great service.

Now on the approach of the close of this 30th Annual Meeting—and Second International Foundrymen's Congress let us propose a theme, which may well become a symphony.

"Let knowledge grow from more to more,
But more of reverence in us dwell
That mind and soul—according well
May make one music as before,
But vaster!"

Your committee proposes to our officers, to our authors, to our hosts of the City of Detroit, to all those who have contributed —personally and in collaboration, to the success of this great meeting, a rising vote of appreciation.

Resolutions—respectfully submitted by

Resolutions Committee

ALFRED E. HOWELL, Chairman,
H. COLE ESTEP,
C. B. CONNELLEY.

A. E. Howell then presented the following resolution:

Whereas we have been informed of the sudden death of Mr. George K. Elliott on September 23rd, on the eve of this meeting of the American Foundrymen's Association, and

Whereas, Mr. Elliott was to have been the Chairman of the Joint Round Table Session of the A. F. A. and the A. I. M. E., and,

Whereas, His absence has been sorely felt by his associates, who hold him in the highest esteem.

Be It Resolved, By the members of the American Foundrymen's Association in meeting assembled, that we deplore the loss of our friend and valued associate, and beg to extend to his bereaved family our sincere sympathy and condolence, and that a copy of this action be conveyed to Mrs. Elliott, and spread upon our minutes.

R. A. Bull moved the acceptance of the resolution. Motion seconded by N. K. B. Patch and unanimously adopted.

Mr. Howell read the following resolution, which upon motion by S. Wells Utley, seconded by R. A. Bull, was unanimously adopted and the Secretary instructed to forward copy to Mr. Mahon:

Whereas, Mr. J. L. Mahon has been one of the most active of the members of the Detroit Foundrymen's Association in arranging for this Convention and administering to the welfare and entertainment of the ladies of our convention, and

Whereas, During the Convention Mr. Mahon suffered the loss by death of his aged father, now be it

Resolved, That the Secretary be instructed to convey to Mr. Mahon the sincere sympathy of the members of this Association in his bereavement, and that a copy of this resolution be spread upon the minutes of this Convention.

Mr. Howell submitted the following resolution, which, on motion duly seconded, was unanimously adopted:

Whereas, The first International meeting of Foundrymen in Paris, France, was a most distinct success; and

Whereas, This Second International Foundrymen's Congress in Detroit, Michigan, still further exemplifies and emphasizes the beneficent results to the Industry we represent and to the world.

Be It Resolved: That the members of the American Foundrymen's Association approve of the plan of holding these Inter-

national Meetings at convenient intervals of about three years, and recognize the very evident beneficial results of such meetings, both from a practical and social standpoint, and we hereby pledge our endorsement and support of the general plan for such International Foundrymen's Congresses as may be suitably arranged in the future.

C. B. Connelley, chairman of the committee to judge entries for the S. Obermayer Award of the American Foundrymen's Association, submitted the following report on behalf of the committee:

To the Board of Directors of the American Foundrymen's Association:

Your committee of judges of the 1926 Obermayer Prize beg to submit the following report:

There were four devices submitted in this competition, all of which, in the opinion of the committee, have merit. The apparatus that seems to be of the most use and can be used more universally, is that submitted by Redfield H. Allen, of the Worthington Pump and Machinery Corporation, East Cambridge, Massachusetts. This, a device for closing door of cupola, herein is described:

"Apparatus consists of a differential chain block (or other suitable hoist), two extension bars which slide into lugs on cupola bottom doors and a two-part chain having rings at ends to slip over ends of extension bars and a ring at center for the hoist hook.

"The hoist is operated until both doors are closed. For the protection of the man who goes under cupola to set the post, a second man inserts an 8 ft. bar in a stirrup and uses it as a pry under the lip door to guard against a possible drop of the doors should a chain break or the hoist fail for any reason.

"After the post is set the hoist is slacked off, extension bars withdrawn, the chains looped back over a hook conveniently located."

Your committee commends Mr. H. V. Fitzgerald, of the Metric Metal Works of the American Meter Works, of Erie, Pa., on his Safety Insulated Pouring Ladle; they also comment

favorably on the Tilting Spout submitted by Carl Aabye, of the Chicago Malleable Casting Company, of West Pullman, Illinois, together with that of the self-forming sprue, by A. E. Shipley, of East Cambridge, Mass.

The committee believes from year to year when the object of this prize is universally known by the foundry industries and their workmen, that there will be keener interest shown about the foundry devices.

We take this opportunity to commend the Obermayer Company for their thoughtfulness and interest in the foundry appliances.

Respectfully submitted,

ROBERT CRAWFORD,
JOHN W. COLLINS,
JOHN J. BOLAND,
FRED ERB,
C. B. CONNELLEY, *Chairman.*

On motion, duly seconded, the report was received and referred to the Board of Directors.

Benjamin D. Fuller presented the following report of the committee of judges of the apprentice molding contest:

To the Members of the American Foundrymen's Association:

Eight iron and three steel castings were submitted in the apprentice molding contest conducted by the American Foundrymen's Association and represented interest taken by the General Electric Co., Erie, Pa., New England Foundrymen's Association; Milwaukee Metal Trades Association; Pusey and Jones, Wilmington, Del.; Quad City Foundrymen's Association, Davenport, Iowa.

The patterns used for all the iron castings were exact duplicates of each other and the patterns for the steel castings were made in a similar manner to standardize the contest as far as possible. Character of sand, style of gates and many other details were left to the individual judgment of the molder.

Steel castings came from the Milwaukee district. Apprentices from industrial plants in the city made the molds in the

foundry connected with the vocational school and poured them from metal melted in an electric steel furnace. Your committee notes that the metal was cold in each case and therefore the surface of the castings impaired. After making due allowance for this feature the first prize was awarded to C. Fuerst, Falk Corp., the second prize to M. Rehbein, Bucyrus Corp., and the third prize to the marker of the remaining casting, A. Bottoni, Falk Corp. Names of the contestants were not given on the identification card which accompanied each casting in a sealed envelope.

Out of the eight iron castings, three were selected as representing the best appearance. Only minor imperfections differentiated the second and third from the first. All three were excellent castings. The first prize was awarded to contestant James R. Loveland, the second to F. Cordel Gillette, and the third to Elmer DeWolf. Singularly enough when the envelopes accompanying the castings were opened it was discovered that all three castings came from the General Electric Co., Erie, Pa.

Respectfully submitted,

EUGENE SMITH,
PAT DWYER
BENJAMIN D. FULLER, *Chairman.*

On motion, duly seconded, the report was referred to the Board of Directors.

D. M. Avey, Chairman, Committee on Pattern Equipment Standardization, submitted a report with recommendations for Board action. On motion, duly seconded, the report was accepted and referred to the Board of Directors.

Chairman Root announced the resignation of W. M. Saunders, as chairman of the Joint Committee on Molding Sand Research, stating that the resignation had been accepted with regrets, and that Benjamin D. Fuller had been appointed to succeed Mr. Saunders as chairman of the committee.

A. E. Hageboeck, chairman of the committee on Foundry Costs, reported on the cost session and submitted resolutions that had been adopted at a members' session. On motion by Mr.

Utley, duly seconded, the report was accepted and referred to the Board of Directors.

R. F. Harrington moved that a committee be appointed to prepare resolutions of appreciation of the services of W. M. Saunders as chairman of the Joint Committee on Molding Sand Research. This motion was duly seconded and carried.

Secretary Hoyt reported that at a meeting of the Board of Directors held September 26th, a resolution had been unanimously adopted recommending to the members that they confer upon President A. B. Root, Jr., at the expiration of his term of office, the title of Honorary Member of the American Foundrymen's Association, Inc.

Past President R. A. Bull moved the unanimous adoption of the recommendation of the Board of Directors. Motion seconded by Mr. Connelley and adopted by a rising vote.

Dr. Geilenkirchen, representing the Verein Deutscher Eisengiessereien (German Foundrymen's Association), addressed the meeting stating that he had been requested to express for Dr. Werner, President of their Association, his regrets as being unable to attend the congress, and desired to express for his Association appreciation for the invitation to the Congress and the opportunities thus presented for the assimilation of knowledge and information from our Convention and our industries.

Dr. Geilenkirchen stated that their Association now has under consideration the issuance of invitations to an International Foundrymen's Congress, which they would propose to be held at Dusseldorf in 1929.

President Root in response returned the assurances of good will and our appreciation of the fine representation of their Association at this Congress. He advised Dr. Geilenkirchen that his remarks regarding the next International Foundrymen's Congress, which it was proposed to hold at Dusseldorf, would be referred at the proper time to our Committee on International Relations for their consideration.

Mr. Hoyt, addressing President Root, commented on the splendid way in which he had conducted the affairs of the Association during a year in which the responsibilities of the President

had been unusually heavy, and called for a rising vote of appreciation for his services.

President Root responded briefly and declared the meeting adjourned.

Session No. 22—Cast Iron Metallurgy
Thursday, Sept. 30, 2:30 p. m.

H. Cole Estep presided.

Papers read and discussed were as follows:

THE DILATOMETRIC ANALYSIS OF MATERIALS, by A. Portevin and P. Chevenard, Paris, France. In the absence of the authors this paper was presented by E. V. Ronceray. This paper was one of the two official contributions presented on behalf of the Association Technique de Fonderie de France.

HEAT RESISTANT CAST IRONS, by O. Smalley, New York City.

THE EFFECT OF VARIOUS ALLOYS ON THE GROWTH OF GRAY IRON UNDER REPEATED HEATINGS AND COOLINGS, by R. R. Kennedy anud G. J. Oswald, National Cash Register Co., Dayton, Ohio.

PHOSPHORUS IN CAST IRON, by J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, England.

PRODUCTION OF HIGH GRADE FOUNDRY IRON, by Dr. E. Piwowarsky, The Technical High School, Aachen, Germany. This paper was presented on behalf of the Verein Deutscher Eisengiessereien.

Session No. 23—Elimination of Waste in the Foundry Industry
Thursday, Sept. 30, 2:30 p. m.

Chairman, C. B. Connelley.

The following committee and A. F. A. representative reports were presented.

A. B. Root presented a report as the A. F. A. representative on the Department of Commerce committee to consider the placing of the weights of castings on blue prints.

S. W. Utley presented a report as the A. F. A. representative on the Dept. of Commerce committee to consider the elimination of waste in the metal industry.

D. M. Avey presented the report of the Joint Committee on Pattern Equipment Standardization.

H. Y. Carson presented the report of the A. F. A. Committee on Corrosion.

Session No. 24—Foundry Sand Control
Friday, Oct. 1, 10:00 a. m.

Major R. A. Bull, Past President of the A. F. A., presided as chairman.

The following papers were read and discussed:

METALLURGICAL CONTROL OF FOUNDRY SANDS, by L. B. Thomas, Fairbanks-Morse Co., Three Rivers, Mich.

GRADING FOUNDRY SANDS, by C. A. Hansen, General Electric Co., Schenectady, N. Y.

THE EFFECT OF MULLING TIME ON SOME OF THE PROPERTIES OF SAND, by A. V. Leun, Cornell University, Ithaca, N. Y.

SOME EXPERIMENTS TO DETERMINE THE EFFECT OF CLAY ON THE FUSION POINT OF MOLDING SANDS, by D. W. Trainer, Cornell University, Ithaca, N. Y.

Annual Banquet

Thursday, September 30, 7:00 P. M.
Hotel Statler

The annual banquet of the Association was held at the Hotel Statler, Thursday evening, September 30, with President A. B. Root, Jr., presiding. J. W. Smith, Mayor of the City of Detroit, on being introduced by President Root extended greetings to the Association and its guests on behalf of the City.

Following Mayor Smith's address, President Root gave a brief review of the early history of the Association and told of the development of the following years. He then presented H. Cole Estep, Chairman of the Committee on International Relations. Mr. Estep introduced the representatives of the overseas foundry associations, who were:

E. V. Ronceray, Vice-President, Association Technique de Fonderie de France.

H. Magdalenat, Vice-President, Association Technique de Fonderie de France.

Dr. E. Geilenkirchen, Managing Director, Verein Deutscher Eisengiessereien of Dusseldorf.

Leon Gerad, Brussels, representing Association Technique de Fonderie de Belgique.

S. H. Russell, Vice-President, Institute of British Foundrymen.

Ing. Carlo Vanzetti, Vice-President, Italian Foundrymen's Association.

T. J. Brons, Cooperative Society of Dutch Iron and Steel Founders.

Don Jose Iturrioz, Representative of the Spanish Foundrymen.

Sixten Nilsson, Representative of the Swedish Foundrymen's Association.

John Cameron, Past President, the Institute of British Foundrymen.

Mr. Cameron responded for the overseas guests.

After Mr. Cameron's response, President Root introduced President-elect S. W. Utley and Vice-President-elect S. T. Johnston.

Past President, L. W. Olson, as Chairman of the Board of Awards, presented the three A. F. A. gold medal awards, which were to be made at this time to Professor Thomas Turner of Birmingham, England; E. V. Ronceray of Thiais, France; and John Shaw of Sheffield, England. Mr. Olson in presenting these medals made the following remarks:

"Mr. President, ladies and gentlemen. In this age of wonderful efficiencies and accomplishments, we have gathered in this second International Foundrymen's Congress. We have come here to greet our friends, renew old acquaintanceships and make new ones. We have come here to exchange experiences and opinions, to see new machinery and inventions. We have come here to get the results of practical and scientific research and to acclaim those whose efforts have resulted in higher efficiencies and accomplishments.

"Efficiency, because of its blunt directness, frequently jars upon our æsthetic and artistic senses. Such a clash can readily occur in foundries. Here most of the effort is directed toward commercial production, so that artistry in design is made secondary to practical considerations. On this occasion and in this assemblage there may perchance be some who have been pleasantly anticipating a presentation of awards oration, and there are no doubt others who are ardent proponents of efficiency and directness in all things, not even banquet speeches excepted. So I hope to be forgiven by the first group and commended by the second group if I courageously combine three presentation speeches into one and even make that one brief.

"We are told by the philosophers that accomplishment is its own reward. Sometimes that is all one receives, but surely such a reward is much more acceptable and prized when our friends and fellow workers also fully believe it has been earned. I like to think that Joseph S. Seaman, John A. Penton, J. H. Whiting and W. H. McFadden had this in mind when a few years ago, in their far-sighted liberality, they entrusted to the American Foundrymen's Association endowment funds from which our Gold Medal awards are made. They must have realized that a public recognition of accomplishment corroborating and confirming the conviction of the individual would complete his satisfaction.

"Like the garlands bestowed upon the ancient athletes, so also the Gold Medals of the American Foundrymen's Association are emblematic of victory. The garlands were perishable but these Gold Medals will remain permanent testimonies to the accomplishment of the recipient and perpetual reminders that his fellow workers were not unmindful of his contribution to our civilization. The Board of Awards, consisting of the last seven living past presidents of this Association, after considerable correspondence and two well attended meetings, decided to award three Gold Medals at this time. In view of the international character of this year's meeting, it was also decided to make all three awards to persons outside of the United States. The Board of Directors have unanimously approved this action of the Board of Awards as well as their selection of medalists, and so it has become my rare privilege to present on behalf of the American Foundrymen's Association the Joseph S. Seaman Gold Medal of the A. F. A. to Prof. Thos. Turner of Birmingham, England. Professor Turner isn't here, but his son will receive the medal for him.

"The John A. Penton Gold Medal of the A. F. A. to Mr. John Shaw of Sheffield, England.

"The J. H. Whiting Gold Medal of the A. F. A. to Mr. E. V. Ronceray of Thiais, France.

"For your information and convenience, your programs contain a brief outline of the experience and accomplishments of

each of these gentlemen. This is rather scant praise for the work they have accomplished, but time will not permit of lengthy eulogies."

Following the presentation of the medals, President Root introduced Mr. C. F. Kettering, Vice-President, in charge of research of the General Motors Corporation, who made the principal address of the evening on "The Advancement of the Scientific Profession of the Country Today."

Annual Report of the Board of Directors

To the Members of the American Foundrymen's Association, Inc.
Gentlemen:

The management of the Association is vested in a Board of Directors consisting of a President, Vice-President, and fifteen Directors. The By-Laws provide that an annual meeting of the Board shall be held within ninety days of the closing date of the annual convention of each year. Special meetings of the Board are called by the President.

The following is a summary of meetings of the Board held during the year 1926:

September 26th at Detroit, Michigan, preceded by Alumni Dinner. Report of Board of Awards received. Convention committees appointed. President A. B. Root, Jr., recommended for Honorary Membership.

The Board voted to hold the next convention in the spring of 1927 without an exhibit.

December 7th, annual meeting of Board of Directors held at Edgewater Beach Hotel, Chicago, President A. B. Root, Jr., presiding. Reports of officers were received. Report of Finance Committee, including recommendations for transfers of funds and appropriations, accepted.

Tentative specifications recommended by J. C. M. S. R. adopted and certain previously adopted tentative specifications advanced to standard specifications.

Report of Committee on Foundry Costs, recommending operating divisions known as Standard Basic Departments as a recommended practice, approved.

Retiring Director Alfred E. Howell presented with a copy of illuminated resolutions expressing appreciation of long, loyal and efficient service.

Iron and Steel Scrap Specifications proposed by the Department of Commerce approved. A. F. A. participation in activities

of Joint Committee on Foundry Refractories approved. Report of Committee on Pattern Equipment Standardization with recommendations for adoption of eleven separate items as recommended practice, approved.

Resolutions on A. F. A. participation in future international foundry congresses adopted. Resolutions of appreciation for work of H. Cole Estep adopted and illuminated copy authorized.

Report of judges for the S. Obermayer Prize accepted. Report of Committee on Apprentice Contests received and awards and prizes authorized. Meeting of old Board adjourned.

The new Board, with President S. W. Utley presiding, organized by electing an Executive Committee, Executive Secretary-Treasurer, Technical Secretary and Manager of Exhibits.

Certain committee appointments for the year announced. Committee appointed to consider policy of issuing preprints.

Edgewater Beach Hotel, Chicago, chosen as place of 1927 convention during week of June 6th.

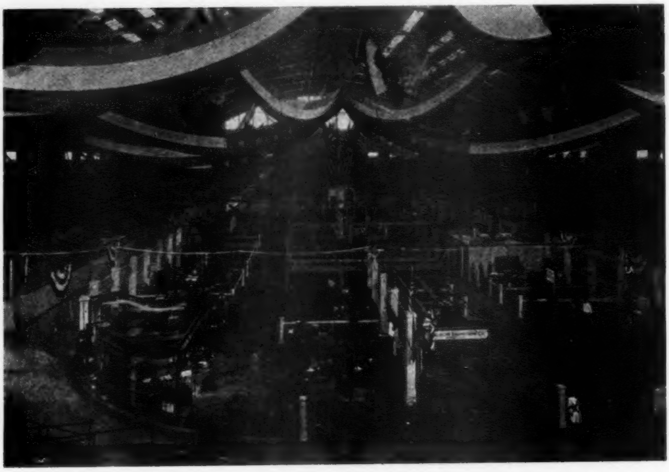
Election by letter ballot of the members of four members of the 1927 Nominating Committee authorized. Resolution for defraying expenses of Directors and committee members in attendance at meetings adopted.

Committee on Convention and Exhibits empowered to select a city and determine date for the 1928 convention and exhibit.

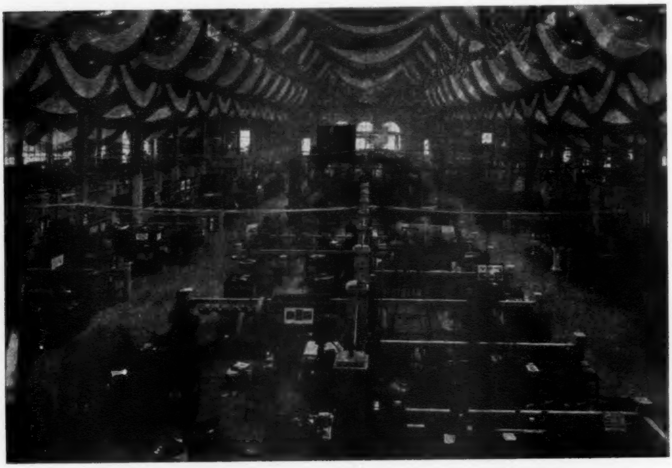
Following is a report of full minutes of all meetings of the Board of Directors for the year 1926.

Respectfully submitted,

C. E. Hoyt,
Executive Secretary-Treasurer
for the Board of Directors.



THE DETROIT EXHIBIT—THE ARENA OF THE COLISEUM



THE DETROIT EXHIBIT—THE DAIRY BUILDING

Report of Manager of Exhibits for the Year Ending December 31, 1926

As a matter of record we submit the following report as a brief summary of the 20th Annual Exhibit of foundry equipment and supplies held in conjunction with the Annual Convention of the American Foundrymen's Association. The exhibit, held in buildings on the Michigan State Fair Grounds, Detroit, opened Saturday, September 25, was closed Sunday, and open daily from Monday, September 27, to Friday, October 1, between the hours of 9:00 A. M. and 5:00 P. M.

There were 267 exhibitors, an increase of 80 over the previous year and exceeding by 21 exhibitors the high mark of 246 established at Columbus in 1920. Forty-six firms exhibited for the first time at an A. F. A. convention. There were 34 exhibitors from the city of Detroit, two from Germany and one from England.

Three exhibit buildings were used. The total space occupied, exclusive of aisles, was 83,500, an average of 312 square feet per exhibitor and exceeding by 7,100 square feet the previous high mark established in 1920.

The total number of carload shipments delivered to the State Fair Grounds was 74; weight of inbound freight shipments, 583 tons; number of inbound express shipments, 451; total weight, 105,350 pounds.

The average price of exhibit space was 77c per square foot. The average price at previous conventions was 74.3c at Syracuse in 1925, 77.4c at Milwaukee in 1924, and 77.8c per square foot at Cleveland in 1923. A financial statement showing income and expense will be found in the auditor's report, which is given with the report of the Executive Secretary-Treasurer.

In addition to paying a building rental of $2,600.00, which did not include power, light, heat, janitor and other service, a bond of $5,000.00 was required for faithful performance of contract. The bond has been discharged and all obligations paid in full.

Respectfully submitted,

C. E. Hoyt, *Manager of Exhibits.*

Minutes of Meeting of Board of Directors, American Foundrymen's Association,

HELD AT

DETROIT CLUB, DETROIT, MICHIGAN,

SUNDAY EVENING, SEPTEMBER 26, 1926

Following the annual Alumni Dinner, a regularly called meeting of the Board of Directors of the American Foundrymen's Association was held, with President A. B. Root, Jr., presiding.

Members of the Board present were A. B. Root, Jr., S. W. Utley, L. L. Anthes, T. S. Hammond, Alfred E. Howell, Thomas W. Pangborn, G. H. Clamer, A. E. Hageboeck, R. A. Nourse, Wm. J. Nugent, Fred Erb, Jesse L. Jones, L. W. Olson, H. S. Simpson and C. E. Hoyt. Directors absent were C. R. Messinger and John E. Galvin.

Others present were R. E. Kennedy, R. A. Bull, W. R. Bean, B. D. Fuller, C. B. Connelley, Dr. Richard Moldenke, V. E. Minich, and Directors-elect S. T. Johnston, S. C. Vessy, L. C. Wilson and N. K. B. Patch.

President Root in calling the meeting to order said that as the minutes of the last Board meeting had been printed in the bound volume of Transactions, he would entertain a motion that their reading be dispensed with. It was so moved.

REPORT ON AWARDS

Secretary Hoyt reported that at a meeting of the Board of Awards held in Detroit, June 7, 1926, it was unanimously voted to recommend to the Board of Directors that the following awards be made in 1926:

To John Shaw of Sheffield, England, the John A. Penton Gold Medal.

To Professor Thomas Turner of Birmingham, England, the Joseph S. Seaman Gold Medal.

To Eugene Victor Ronceray of Thiais, France, the J. H. Whiting Gold Medal.

The Secretary further reported that the recommendations of the Board of Awards were submitted by letter ballot to the Board of Directors and were by them unanimously approved; that following the action of the Board each of the candidates had been notified and acceptances had been received from all; that medals had been struck, certificates prepared and presentation was to be made at the annual banquet Thursday evening, September 30th.

On motion duly seconded, it was voted that the report of the Board of Awards be made a matter of record in the minutes of this meeting.

Resignation of W. M. Saunders

President Root announced that W. M. Saunders, Chairman of the Joint Committee on Molding Sand Research, had tendered his resignation to take effect at the time of the annual convention, and that past President Benjamin D. Fuller had been appointed to succeed Mr. Saunders as General Chairman of the Joint Committee.

On motion duly seconded the resignation of Mr. Saunders was accepted and the appointment of Mr. Fuller confirmed.

Mr. Fuller, who was present, responded, saying that he would give his very best efforts to this work and requested the co-operation and support of Board members.

Committee on Obermayer Award

President Root appointed C. B. Connelley chairman of a committee to judge the entries for the Obermayer Award Prize of the A. F. A., he to select the other members of the committee.

Welcome to Overseas Delegation

President Root reported the reception given to the overseas delegates in New York, where they were given a dinner of welcome at the Pennsylvania Hotel on the evening of September 21st. Mr. Clamer reported on the reception given the delegation in Philadelphia, from where they went to Buffalo and were tendered a reception and dinner by the foundrymen of that city.

President Root announced that the delegates were on their way via boat from Buffalo to Detroit and would dock at 9:00 A. M. the following morning, and requested that all who could conveniently do so, go with him to meet the delegation when they arrived.

Messrs. Minich, Clamer, Root, Hoyt and others commented on the splendid work of Mr. Estep in arranging all the details for the reception and entertainment of overseas delegates.

On motion by Mr. Clamer, seconded by Mr. Minich, it was unanimously voted to instruct the President to appoint a committee of three to draft resolutions of appreciation to be engrossed and presented to Mr. Estep. President Root named as members of the committee A. E. Howell, G. H. Clamer and R. A. Bull.

President Root Recommended for Honorary Membership

Past-President L. W. Olson said that it was his pleasure to move that the Board of Directors recommend to the members of the Association at the annual business meeting that they confer upon retiring President A. B. Root, Jr., at the expiration of his term of office, the title of Honorary Member of the American Foundrymen's Association, Inc.

There were many seconds to the motion, which was put by Mr. Olson and unanimously carried.

Committee on Resolutions

The President announced that he would appoint as a Committee on Resolutions for this Convention Alfred E. Howell, Chairman, C. B. Connelley and H. Cole Estep.

Report of Committee on Place of 1927 Convention and Exhibit

Secretary Hoyt reported that at the last annual Board meeting authority was delegated to the Executive Committee to determine the place of the 1927 annual meeting, if it was found advisable to make a decision before the next meeting of the Board.

The Secretary further reported that on June 7th a joint meeting of the Executive Committee and the Committee on Convention and Exhibits was held in Detroit, at which time it was voted to recommend to the Board of Directors that the 1927 convention and exhibit of the Association be held in Philadelphia in the month of September or October.

It was moved and seconded that the report of the committee be accepted.

President Root in calling for remarks commented upon the many conventions and exhibits of allied industries that were annually held in the fall of the year, seriously conflicting with the best interests of A. F. A., and invited discussion on the advisability of holding the annual meetings in the spring of the year.

Each Board member and Alumni member present was called on. Expressions were almost unanimous in favor of spring meetings. The motion to accept the report of the committee was withdrawn, whereupon it was moved that the report of the committee be laid upon the table.

It was moved that the next annual meeting of the Association be held in the months of May or June, 1927, without an exhibit, and that in the spring of 1928 there be held an annual convention of the Association with exhibits. Motion prevailed.

Time and Place of 1927 and 1928 Meetings

It was moved that the time and place for holding the 1927 and 1928 annual meetings be referred to the Committee on Convention and Exhibits, who would make a survey and report to the Board of Directors at the annual meeting. Motion seconded and unanimously carried.

During the discussion on holding a convention without an exhibit, Wells Utley stated that he was far more interested in the best interests of the Association than he was in seeing a large record convention during his year as President, and that he would be happy to be the first president of the Association in years to hold a successful convention without an exhibit.

R. A. Bull moved that those present express their appreciation of the very liberal attitude Mr. Utley had taken in the discussion of this question.

RESOLUTION OF APPRECIATION

It was moved that the Secretary be instructed to express to Harry Standard of the Northern Engineering Works, appreciation for his courtesy in arranging for the Alumni Dinner at the Detroit Club. Motion unanimously prevailed.

ADJOURNMENT

There being no further business, it was moved that the meeting of the Board adjourn to meet again during the week at the call of the President, if such a meeting was found advisable.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Approved: Dec. 7, 1926.

Minutes Annual Meeting of Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION

AT

CHICAGO, DECEMBER 7, 1926

Meeting called to order by President A. B. Root, Jr., at Edgewater Beach Hotel, 10:00 a. m.

The following responded to roll call: President A. B. Root, Jr., Vice-President S. W. Utley, Technical Secretary R. E. Kennedy, Directors L. L. Anthes, G. H. Clamer, Fred Erb, A. E. Hageboeck, Alfred E. Howell, C. E. Hoyt, Jesse L. Jones, R. A. Nourse, Wm. J. Nugent, L. W. Olson, and H. S. Simpson. Directors-elect M. W. Henley, N. K. B. Patch, S. C. Vessy and L. C. Wilson were also present. S. T. Johnston arrived later.

APPROVAL OF MINUTES

Minutes of the Annual Board Meeting held December 8, 1925, were approved as printed in bound volume of Transactions No. 33.

READING OF MINUTES

Minutes of the meeting of the Board held at Detroit, September 26, were read and approved as read.

Report of Executive Secretary

Executive Secretary C. E. Hoyt read his annual report for the Board. On motion duly seconded the report was accepted and ordered placed on file.

Report of Manager of Exhibits

C. E. Hoyt, Manager of Exhibits, submitted his annual report for the department of exhibits and on motion duly seconded the report was accepted and ordered placed on file.

Report of Treasurer

Treasurer Hoyt submitted his report for the department of exhibits, typed copies of which had been made for each member of the Board of Directors showing detail of receipts and expenditures. On motion duly seconded the report was accepted and ordered placed on file.

The report of the Treasurer for the technical department was submitted and on motion duly seconded was accepted and ordered placed on file.

The Treasurer submitted a report covering the special funds of the Association, including the Rogers Brown Fund, the Cleveland Research Fund and the Reserve Fund, stating that the report of the Finance Committee would contain recommendations covering these funds. On motion duly seconded the report was accepted and ordered placed on file.

Confirmation of Letter Ballot on Permit Fees

The Secretary stated that on April 21st the Directors by letter ballot voted unanimously to credit exhibitors permit fees to the technical department. Mr. Utley moved that this ballot be confirmed by the Board. Motion seconded by Mr. Howell and carried.

Report of Finance Committee

The report of the Finance Committee, consisting of President A. B. Root, Jr., Vice-President S. W. Utley, and Vice-President-elect S. T. Johnston, was submitted by Mr. Utley, Chairman. Mr. Utley presented an operating statement for the department of exhibits as taken from the books December 1st and estimated expenses to January 1st, and submitted the following recommendations:

First, In lieu of taking from the reserve fund the sum of $1,250.00 as authorized by the 1925 Board for research work, the committee recommends reimbursing the general technical department fund from 1926 surplus of the exhibit department the sum of $600.00, being the amount spent for sand research over and above funds on hand at the beginning of the year.

Second, That the sum of $1,600.00 from 1926 exhibit department surplus be transferred to the technical department molding sand research account to furnish funds for 1927 work.

Third, The authorized withdrawal from the reserve fund of $1,250.00 for molding sand research, and a like amount for research in cast iron, have not been used and automatically revert back into the reserve fund.

Fourth, In view of the fact that no exhibit will be held during 1927, we do not recommend the transfer of any money from operating funds to the reserve fund, and do recommend that the Finance Committee be empowered by the Board to take such steps as may be necessary to finance operations.

Technical Funds

Mr. Utley then read an operating statement for the technical department showing estimated balance as of January 1, 1927, if the recommended transfers were not made and if they were made, and offered the following recommendations:

First, We recommend that the technical department be reimbursed by the transfer of $943.87 from the awards interest fund, and that until otherwise voted awards expenses be taken from awards interest fund.

Second, We recommend that the money in the Cleveland Research Fund, amounting to $1,377.75 plus interest, and in the Rogers Brown Fund, $543.99 plus interest, be made available for use for other research work at the direction of the Finance Committee.

Third, The committee recommends the usual contribution to the Institute of Metals Division of $250.00.

The Chair stated that in order that the report of the Finance Committee as a whole might be entered upon the records, he would ask for a motion for its acceptance. On motion by Mr. Howell duly seconded the report of the Finance Committee was accepted as read.

The Chair then called for a vote on each recommendation of the committee separately. On motions duly seconded all the recommendations of the committee were approved.

Report for Executive Committee

Secretary Hoyt stated that no meetings of the Executive Committee had been held since the last Board meeting.

Report of Technical Secretary

Technical Secretary Kennedy submitted a report covering the work of the department. On motion duly seconded, the report was accepted and ordered placed on file.

Report for Joint Committee on Molding Sand Research

Reports covering this work were submitted by Chairman B. D. Fuller and Secretary Kennedy. On motion by Mr. Erb, duly seconded, the report was accepted and the Chair announced that the recommendations of the committee would be taken up.

Mr. Hageboeck moved and Mr. Utley seconded, that the following recommendations of the committee be adopted:

1. Method of testing core sand by briquette method, specifying method only, not apparatus, to be adopted as tentative standard.
2. Grading of molding sand:
   (a) Grain fineness classification, 1 to 10.
   (b) A similar classification of clay content by letters A to J inclusive.

   To be adopted as tentative standard.
3. That the following methods be advanced from tentative standard to standard:
   (a) Fineness test.
   (b) Chemical analysis.
   (c) Method of sampling sand as shipped or delivered.
   (d) Permeability test.

Following brief discussion the motion was unanimously adopted.

Resignation of N. R. C.

Mr. Utley moved that the resignation of the National Research Council as members of the Joint Committee on Molding Sand Research be accepted. Motion seconded and unanimously carried.

Report for Committee on Foundry Costs

Mr. Hageboeck, Chairman of the Cost Committee, submitted a report which included recommendations of the committee adopted at a meeting held the previous day and a resolution adopted at the members' session at the annual convention, which was as follows:

Resolved: That it be the sense of this meeting that the American Foundrymen's Association take up cost work vigorously and push forward the work of the committee as fast as possible; and part of the work of the committee should be to urge the adoption by local community foundrymen's associations of a uniform cost system to be adapted to their own needs in conference with the American Foundrymen's Association Cost Committee.

Lengthy discussion of the report ensued, following which President Root offered the following recommendations:

That this Board approve the resolution adopted at the Cost Session at the Detroit Convention with the following reservation: that the Cost Committee should not institute movements for the creation of local groups as referred to.

That it further approve the use of the operating divisions known as "Standard Basic Departments," as a "Recommended Practice" for the guidance of those wanting help in their cost problems.

That we further approve the suggestion of the Cost Committee for the enlargement of its committee by the appointment of sub-committees

on gray iron, malleable, steel and non-ferrous groups as outlined in their report.

That any further direction or modification of the operations of the Cost Committee be decided by the Executive Committee in the interval between this and the next meeting of the Board.

Mr. Hageboeck stated that he personally would be pleased to accept the recommendations read by Mr. Root as the report of the Cost Committee.

Mr. Nugent moved that the report of the committee be accepted as amended by the recommendations offered by Mr. Root. Motion seconded by Mr. Erb and unanimously carried.

Mr. Clamer moved that it is the sense of this Board that we back all the work of the Cost Committee that is of an educational nature. Motion seconded and unanimously carried.

Alfred E. Howell Luncheon

At this point the meeting adjourned for luncheon. When the members were assembled, President Root announced that this would be an Alfred E. Howell Luncheon in honor of the seventeen years of Mr. Howell's continuous service as an officer or director of the American Foundrymen's Association. President Root announced that he had appointed Past Presidents R. A. Bull, B. D. Fuller and G. H. Clamer as a Committee on Program and would turn the meeting over to them.

Major Bull as Chairman of the committee spoke briefly and feelingly of Mr. Howell's long service and then read the following resolutions:

ALFRED E. HOWELL

Past-President and Honorary Member
of the
American Foundrymen's Association

Has placed the officers, directors and members of our Association under lasting obligations, as the result of exceptionally active, constructive service, maintained continuously throughout his membership on the Board of Directors for seventeen years.

During this period, the Association added to its prestige by selecting as its President, and subsequently as one of its Honorary Members, him to whom we now pay this tribute, acknowledging our deep indebtedness for wise counsel and tactful guidance at critical times.

The Creator gives to but a chosen few, souls so attuned that their innermost chords vibrate only to that which is finest in life. Such a soul has Alfred Howell.

Those who are and those who have been officers and directors of the American Foundrymen's Association, and who are now in meeting assembled, instruct the President, the Vice-President and the Secretary

of the Association, on behalf of the members of its alumni circle, to present to Alfred Howell, able foundry executive and cultured devotee of the fine arts, this written testimonial of warm appreciation and personal regard.

On motion the resolutions were unanimously adopted by the Board, and Major Bull continuing said that anticipating this action, the committee had had the resolutions illuminated and mounted in a leather case. He then presented them to Mr. Howell.

Major Bull called on Past President B. D. Fuller, who presented on behalf of the Association a writing set, consisting of a fountain pen desk stand, pocket pen and pencil.

Following Mr. Fuller's presentation, Major Bull called on Past President G. H. Clamer, who presented on behalf of the Board of Directors a handsomely engraved gold cigarette case.

Following these presentations Mr. Howell responded in his own characteristic manner, expressing appreciation for the privilege of having served the Association so long, the joy and satisfaction he had experienced in doing so, and the hope that he would be privileged to renew at frequent intervals during the coming years the contacts and associations he had enjoyed so much.

Following luncheon the meeting was again called to order with President Root in the Chair.

Report for Committee on Gray Iron Castings

Mr. Jesse L. Jones, Chairman, read a report covering the work of the committee during the past year. On motion the report of the committee was accepted and program for committee activities for the coming year approved.

Mr. Jones moved that the Board approve the classification of Iron and Steel Scrap Specifications proposed by the Department of Commerce and issued by the Bureau of Standards, July 1, 1926, and that these specifications be recommended to our members for use as far as local conditions of supply under such specifications are practical or useful. Motion seconded and carried.

Report for Committee on Phosphorus and Sulphur in Steel

Major R. A. Bull, A. F. A. representative on the Joint Committee on Phosphorus and Sulphur in Steel, reported and requested the Secretary to read the resolution adopted at the members' sessions at the Detroit Convention, which was as follows:

Resolved: That it is the sense of this meeting that the A. F. A. support the program of the Joint Committee on Investigation of the Effect of Phosphorus and Sulphur in Steel for the investigation of the effect of phosphorus in steel castings, provided this investigation is confined to coupons.

On motion by Mr. Nugent, seconded by Mr. Howell, the report and the resolution was unanimously approved.

Report for Committee on Foundry Refractories

Mr. Kennedy submitted a written report reviewing the organization, representation and activities of the Joint Committee. The report requested an expression showing the attitude of the Board in the matter of the extent of A. F. A. participation in this committee work. On motion duly seconded the report was accepted.

Mr. Root then offered the following resolution:

Resolved: That the Board of A. F. A. approve the objects of the Joint Committee on Foundry Refractories and will be glad to co-operate in that work as voted by its Executive Committee.

Motion seconded by Mr. Clamer and unanimously carried.

Report for Committee on Pattern Equipment Standardization

Mr. Kennedy presented a written report listing items which the committee recommended, for the Board's adoption as recommended practice and others as tentative standards. On motion duly seconded the report of the committee was accepted.

Mr. Root then read for approval by the Board the committee's recommendations, the adoption of 11 separate items as recommended practices of the American Foundrymen's Association as follows:

1. Procedure to be followed in marking gaged surfaces on patterns.
2. Procedure to be followed in marking chilled surfaces on patterns and of metal inserts.
3. Formula for obtaining proper coloring ingredients for pattern marking.
4. Pattern letters to be used in marking patterns.
5. Procedure to be followed in marking patterns and core box loose pieces.
6. Schedule of sizes for leather fillets.
7. Schedule of sizes of core prints for metal core boxes.
8. Schedule of sizes of steel dowel pins for metal patterns and core boxes.
9. Lug design for match plates.
10. Size and position of vibrator holes in match plates.
11. Match plate thickness.

Mr. Kennedy stated that these recommendations of the committee were the result of two or three years' investigation, and that with the exception of two, the committee were unanimous in favor of them. Mr. Clamer moved their adoption. Motion seconded by Mr. Howell and unanimously carried.

Mr. Root then submitted the following as recommendations for adoption as tentative standards:

(a) Size of hole in match plates for vibrator bolts.
(b) Position of vibrator bolt hole in match plates.
(c) Shape of match plate end of vibrator.

International Foundry Congresses

Following a report on the Detroit Congress and discussion on future international meetings, the following resolution was adopted:

Resolved, That this Board approve as policy that section of the resolution adopted at the general session at Detroit which reads as follows: "Be It Resolved, That the members of the American Foundrymen's Association approve of the plan of holding these international meetings at convenient intervals of about three years, and recognize the very evident beneficial results of these meetings both from a practical and social standpoint, and we hereby pledge our endorsement and support of the general plan for such international foundrymen's congresses as may be suitably arranged in the future," with the further resolution that on the necessity arising, the Executive Committee be authorized to appoint a representative to participate in a conference to consider the question of continuing international congresses.

Resolutions of Appreciation for H. Cole Estep

Mr. Howell, Chairman of the committee appointed at the Board meeting on September 6th to prepare resolutions of appreciation for the work of H. Cole Estep, read the following:

THE AMERICAN FOUNDRYMEN'S ASSOCIATION

By unanimous action of its
BOARD OF DIRECTORS

desires to record an APPRECIATION of the most gratifying work of H. COLE ESTEP, Chairman of its Committee on International Relations. Previous to the first International Foundrymen's Congress held in Paris in 1923—Mr. Estep, while resident in London, had done much to cement the relations of the foundrymen of several nations—in fact from the inception of the idea of the International Congress Mr. Estep has been indefatigable in assisting to develop it.. Through his broad acquaintance, his zeal, his comprehensive knowledge of and sympathetic attitude toward the casting industry, and his agreeable personality, he contributed very effectively to the great success of the SECOND INTERNATIONAL FOUNDRYMEN'S CONGRESS in Detroit, September 25 to October 1, 1926

We instruct that this recognition of the valuable service of MR. ESTEP be recorded on our minutes and that a copy in permanent form be delivered to him, thus conveying our enduring esteem and appreciation.

On motion duly seconded the resolutions were unanimously adopted.

1926 Obermayer Prize of A. F. A.

The Secretary read the report of the judges presented at the annual business meeting and on motion referred to the Board of Directors. On motion duly seconded the report of the committee was accepted and the Secretary instructed to secure a suitable prize and have prepared a cer-

tificate to be presented to Redfield H. Allen, Worthington Pump & Machinery Corp., East Cambridge, Mass., whose entry in the contest was a device for closing the bottom doors of a cupola.

Report of Committee on Apprentice Contest

The Secretary read the report of the committee presented at the annual business meeting, accepted and referred to the Board of Directors. On motion duly seconded the report of the committee was approved and the Secretary instructed to have prepared suitable certificates for the successful contestants in the apprentice contest, and that cash prizes of $15.00, $10.00 and $5.00 for first, second, and third place winners accompany the certificates.

Report of Committee on Place of 1927 Convention

The Secretary submitted a report for the Committee on Convention and Exhibits, giving the result of the letter ballot on location. On motion the report was accepted and referred to the incoming Board.

Report of Election of Officers and Directors

The Secretary reported that at the annual business meeting of the Association in Detroit, September 30, 1926, the election of the following officers and directors was confirmed:

For President to serve for one year, S. W. Utley,
For Vice-President to serve for one year, S. T. Johnston,
For Directors to serve for three years: Martin W. Henley, N. K. B. Patch, A. B. Root, Jr., S. C. Vessy and L. C. Wilson.

Approval of Acts of Committees of the Board

On motion duly seconded the Board approved all acts of committees of the Board during the past year.

Appreciation

Mr. Nourse moved that the Board extend a vote of thanks to the retiring members for services rendered and appreciation for the able and courteous conduct of Association matters by the retiring President, A. B. Root, Jr. Vice-President Utley put the motion, which was unanimously adopted.

Adjournment

Mr. Root responded by expressing appreciation of the very great co-operation he had received from all officers and members of the Board, making special mention of the great assistance of Mr. Utley during the Detroit Convention. Mr. Root then declared the meeting of the 1926 Board adjourned and turned the gavel over to incoming President S. W. Utley.

Respectfully submitted,

A. B. Root, Jr., President,
C. E. Hoyt, Executive Secretary.

Minutes of First Meeting, 1926-27 Board of Directors

American Foundrymen's Association

Edgewater Beach Hotel, Chicago, December 7, 1926

In accepting the gavel from retiring President A. B. Root, Jr., Mr. Utley responded to the expressions of appreciation made by Mr. Root, addressed the Board on the responsibilities of the position he was assuming, asked for their co-operation and kind consideration at all times, and instructed the Secretary to call the roll:

Roll Call

The following responded to roll call: President S. W. Utley; Vice-President S. T. Johnston; Technical Secretary R. E. Kennedy. Directors G. H. Clamer, Fred Erb, A. E. Hageboeck, Martin W. Henley, C. E. Hoyt, Jesse L. Jones, R. A. Nourse, Wm. J. Nugent, L. W. Olson, N. K. B. Patch, A. B. Root, Jr., H. S. Simpson, S. C. Vessy and L. C. Wilson. Absent, John E. Galvin.

Others present were L. L. Anthes, R. A. Bull, B. D. Fuller and A. E. Howell.

Organization of New Board

It was moved and seconded that the Chair appoint a Nominating Committee to nominate officers and executive committee members to be elected by the Board in accordance with provisions of the By-Laws. The Chair appointed Messrs. S. T. Johnston, S. C. Vessy and G. H. Clamer, who retired to prepare a report.

Report of Nominating Committee

Mr. Johnston, Chairman: Mr. President and Gentlemen of the Board: Your committee has consulted and begs to make the following recommendations:

1. For four members of the Executive Committee, to serve with the President, Vice-President and Executive Secretary, we nominate Wm. J. Nugent, L. W. Olson, A. B. Root, Jr., and L. C. Wilson.
2. The committee recommends that the offices of Executive Secretary, Treasurer and Manager of Exhibits be combined in one, and we nominate C. E. Hoyt for the office of Executive Secretary, Treasurer and Manager of Exhibits.
3. For the office of Technical Secretary we nominate Robert E. Kennedy.

Mr. Nourse moved that the Chair cast one ballot for the nominees named by the Nominating Committee. Motion seconded by Mr. Patch and carried, whereupon the Chair announced that the unanimous ballot

had been cast for the Board and declared all candidates elected to the respective offices for which they had been named in the report of the Nominating Committee.

Salaries

Officers elected C. E. Hoyt and R. E. Kennedy retired from the room while the Board went into executive sessions to consider salaries for the coming year. Mr. Utley, Chairman of the Finance Committee yielded the Chair to Mr. Root and made the following recommendations for the committee:

That the salary of C. E. Hoyt as Executive Secretary-Treasurer be $5500.00, $2750.00 to be paid by the technical department and $2750.00 by the department of exhibits.

That the salary of R. E. Kennedy as Technical Secretary to be $4800.00, paid from the funds of the technical department.

That the salary of C. E. Hoyt as Manager of Exhibits be $6500.00, paid from the funds of the department of exhibits.

That the monthly salary of Miss J. Reininga, Assistant to Secretary-Manager, be $250.00, $75.00 to be paid from the technical department and $175.00 by the department of exhibits.

Mr. Clamer moved the acceptance of the report of the Finance Committee, which was seconded and unanimously carried.

On motion duly seconded the President and Executive Secretary were authorized to employ such office assistance as was found necessary to take care of Association activities.

Disbursement of Funds

The following resolutions for the disbursement of funds were read:

Resolved, That checks for the withdrawal of funds deposited in the name of the Association at the Harris Trust & Savings Bank, Chicago, Chicago Trust Co., Chicago, and Central National Bank Savings & Trust Co., Cleveland, be signed by S. W. Utley as President, or C. E. Hoyt as Secretary-Treasurer, and countersigned by S. W. Utley as President or S. T. Johnston as Vice-President.

Be It Further Resolved, That the resolutions required by the aforesaid mentioned banks authorizing the withdrawal of funds of the Association in accordance with the above resolution are hereby approved and adopted.

Be It Further Resolved, That the President and Secretary are hereby authorized to open an account in the convention city for a special convention fund, they to determine how this account shall be opened and the signatures required for the withdrawal of said funds.

Be It Further Resolved, That the Board authorize a Secretary-Manager's petty cash fund of $500.00, said fund to be reconciled at the end of each month by a full statement of expenditures.

Be It Further Resolved, That in accordance with Section 4, Article 5, of the By-Laws, C. E. Hoyt as Treasurer of this Association shall give

a bond to the amount of $5,000.00, the premium on said bond to be paid by the Association.

The adoption of the resolutions as read was moved, seconded and unanimously carried.

Audit of Books

On motion duly seconded the President was authorized to engage an auditor to audit the books as of December 31, 1926.

Committee Appointments

On motion duly seconded the President was authorized to make all appointments for standing and special committees that are not provided for in the By-Laws or by special act of the Board.

President Utley announced the following committee appointments:

For the Committee on Convention and Exhibits: G. H. Clamer, T. S. Hammond, Thos. W. Pangborn, A. B. Root, Jr., H. S. Simpson and Albert Walton, who together with the President, Vice-President and Executive Secretary will constitute the committee for the coming year.

For the Committee on International Relations: H. Cole Estep, Chairman, G. H. Clamer, L. L. Anthes, Vincent Delport, V. E. Minich and Stanley G. Flagg, Jr.

Joint Committee on Molding Sand Research: Mr. Kennedy, Secretary of the committee, read a list of names who were recommended by the Executive Committee of the J. C. M. S. R. for approval and appointment by the Board. On motion duly seconded the recommendations were accepted and appointments made.

The Chair stated that the technical committee appointments for the coming year would be announced later.

Committee on Metals Utilization

President Utley, the A. F. A. representative on this committee of the Department of Commerce of the U. S. A. during the past year recommended that this representation be continued and that we set up an organization as follows: the representative of the A. F. A. on the Metals Utilization Committee to be chairman of a general committee, on which there would be representatives of the gray iron, malleable, non-ferrous and steel casting industries, with perhaps one or two others to represent special interests.

He further recommended that under the general committee there be sub-committees of which each member of the general committee would be chairman. The duties of the sub-committees would be to consider in their own line of industry the question of waste elimination and report to the Department of Commerce.

On motion duly seconded the recommendations of the President were approved and the appointment of a committee and sub-committees authorized.

Distribution of Preprints

It was moved, seconded and carried that the President appoint a committee to consider the question of issuing preprints, the findings of the committee to be reported to the Executive Committee with power to act.

Appropriation for Cost Work

Mr. Clamer moved that the Board authorize an expenditure of $300.00, if needed, for the work of the Cost Committee during the coming year. Motion seconded and carried.

Activities of Joint Committee on Molding Sand Research

On motion duly seconded the Board approved of the plan of the Chairman of the Joint Committee on Molding Sand Research arranging for demonstrations of sand test methods at meetings of local associations.

1927 Convention

Following discussion on the question of time and place, Mr. Root moved that the next annual convention of the Association be held in Chicago, June 6, 7, 8 and 9, 1927, and that the question of headquarters and arrangements be referred to a sub-committee of the Committee on Convention and Exhibits. Motion seconded by Mr. Vessy and unanimously carried.

Mr. Hoyt outlined a tentative program for the convention as follows: Monday, June 6, registration and committee meetings. Opening sessions of convention 10:00 a. m., Tuesday. Closing session Thursday p. m. Annual alumni dinner Thursday evening.

Mr. Root moved that the Board approve the tentative program as outlined, subject to such changes as the Convention and Exhibits Committee deem necessary. Motion seconded and unanimously carried.

Exhibits

Mr. Simpson moved that in view of the decision to hold a convention without exhibits, the Board to go on record as being opposed to exhibits of any character in the lobbies of hotels, near any place of meeting, or in any private room in a hotel named as headquarters. Motion seconded by Mr. Vessy and unanimously carried.

Annual Board Meeting 1927

Mr. Root moved that the next annual meeting of the Board of A. F. A. be held Thursday evening, June 9, of convention week. Motion seconded by Mr. Vessy and unanimously carried.

Obermayer Award

Mr. Olson moved that owing to the short period of time between the 1926 and 1927 conventions, there be no Obermayer Prize Contest at the next convention. Motion seconded and unanimously carried.

1927 Nominating Committee

Mr. Vessy moved that in accordance with authority vested in the Board, as provided in Article 9, Section 1 of the By-Laws, provision be made for the election of four members of the Nominating Committee by letter ballot of the members. Motion seconded and carried.

The Board then prepared a list of members representing various sections of the country and different branches of the casting industry, whose names, together with others submitted by members, should appear on the ballot for members and alternate members of the Nominating Committee. The following names were proposed:

Walter H. Holt, Pressed Steel Car Co., McKees Rocks, Pa.
George A. Ray, Taylor & Fenn Co., Hartford, Conn.
L. S. Peregoy, Sivyer Steel Casting Co., Milwaukee, Wis.
Walter H. Geier, Modern Foundry Co., Cincinnati, Ohio.
Wm. E. Paulson, Thos. Paulson & Son, Inc., Brooklyn, N. Y.
W. C. Carter, Link-Belt Co., Chicago, Ill.
R. F. Flintermann, Michigan Steel Casting Co., Detroit, Mich.
Dan M. Avey, Penton Publishing Co., Cleveland, Ohio.

Committee Meeting Expenses

The following resolution, on motion duly seconded, was unanimously adopted:

Resolved, That the Secretary-Treasurer be authorized to reimburse Directors and committee members for travelling expenses for attendance at any regularly called Board or committee meetings, except such meetings as are held at the place and during the time of the annual convention of the Association.

Authority of Executive Committee

On motion duly seconded the following resolution was adopted:

Resolved, That the Executive Committee of this Board be empowered to act for the Board in the interim between Board meetings on all matters requiring Board action.

1928 Convention and Exhibit

Mr. Olson moved that the Board empower the Committee on Convention and Exhibits to select a city and determine the date of the 1928 convention and exhibit. Motion duly seconded and carried.

Adjournment

On a motion duly seconded the meeting adjourned.

Respectfully submitted,

S. W. Utley, President,
C. E. Hoyt, Executive Secretary.

Annual Report of Secretary-Treasurer

To the President and Members of the American Foundrymen's Association, Inc.

Gentlemen:

It is always gratifying to review and summarize the work of the Association for a year in which records have been established and unusual activities taken place. The most important event each year in A. F. A. is the Annual Convention. It is in fact the greatest event of the year for the Casting Industry of America.

International Congress

In recording the events for the year 1926, it is proper to place first in importance the International Congress, the first official Foundrymen's Congress ever held in America.

Official delegates were in attendance from Belgium, Denmark, France, Germany, Great Britain, Holland, Italy, Luxembourg, Spain, Sweden, and Switzerland. Unofficial delegates attended from Austria, Australia, Czechoslovakia, and Japan. There were in all nearly 150 in attendance from overseas.

On landing at New York, the official delegates were tendered a dinner of welcome, President A. B. Root, Jr., presiding. Leaving New York the delegations were entertained by committees of foundrymen at Philadelphia and Buffalo en route to Detroit, and at Chicago, Cleveland and Pittsburgh following the Convention. All arrangements for the above itinerary and program of entertainment for overseas guests were handled by the A. F. A. Committee on International Relations, of which H. Cole Estep is Chairman.

Awards to Overseas Members

It was fitting that on this occasion the achievements of three members from overseas be recognized by conferring on Thomas Turner of Birmingham, England, an Honorary Member of A. F. A., the Joseph S. Seaman Medal, on John Shaw of Sheffield,

England, the John A. Penton Medal, and on E. V. Ronceray of Thiais, France, the J. H. Whiting Medal of the American Foundrymen's Association. The making of these awards is recorded in the summary of proceedings in this volume.

Technical Activities

Under the efficient leadership of Technical Secretary R. E. Kennedy, and with the splendid cooperation of the Papers Committee, a program was presented at the Detroit Convention that excelled in quality and exceeded in number of papers any previous convention of A. F. A.

Convention Attendance

All records were broken for attendance. The total number of members registered was 5732, number of ladies 469, number of firms represented 2320, number of states represented 39. States leading in attendance were Michigan 1482 (from Detroit alone 965), Ohio 1040, Illinois 638, New York 549, Pennsylvania 517, Indiana 264, Wisconsin 216, and total from Canada 201.

Membership

Membership records also were broken. On September 1st the two thousand mark was passed and the book membership on December 31st was 2176. Following is a complete membership report for the year:

Book Membership January 1, 1926			1754
New Members during 1926.......		501	
Delinquents dropped in 1926......	19		
Resignations for 1926............	58		
Removed by death..............	2	79	
Net Gain for 1926..............			422
Book Membership December 31, 1926			2176

Finances

Association finances are kept in two separate accounts, one for the department of exhibits and one for the technical department. The books are audited annually by a Certified Accountant under the direction of the Finance Committee, consisting of the President, Vice-President and Vice-President-elect. The sources of income are from members' dues, subscriptions to publications, exhibitors' permits, sale of exhibit space and bank interest.

The total from the above sources for the year ending December 31st was $100,929.54. The total expenses for the same period were $91,292.85. Net income $9,636.69. These figures do not include interest from the reserve fund, reserve fund bonds, award fund bonds, and special research funds. The auditor's report which follows shows condensed balance sheet, condensed statement of income and expenses, detail statement of expenses for the technical department, detail statement of expenses for the exhibit department, and balance sheet showing total assets and liabilities.

Exhibits B, C, D and E and Schedules I, II and III of the auditor's report are on file in the offices of the Executive Secretary-Treasurer, President S. W. Utley and Past President A. B. Root, Jr., available to any members interested in examining them.

Unusual Opportunities

With the Association on a sound financial basis, and a membership which in point of number of member firms leads all foundrymen's associations of the world, the opportunities for constructive work are greater than ever before in the history of the Association.

Members are urged to cooperate with the directors, officers and committees in carrying on the work and in helping to put into practical use, for the advancement of the industry, the results of investigations and researches.

Official Acts

The reports of the Annual Meetings, the Board of Directors, the minutes of all meetings of the Board of Directors, and the

report of the Manager of Exhibits appearing elsewhere in this volume record all the official acts of the Association and its Boards for the year 1926.

We acknowledge with sincere appreciation the support of members and the cooperation of authors of papers and reports whose contributions made for a successful year.

We expressly acknowledge the splendid support of retiring President A. B. Root, Jr., Vice-President and President-elect S. W. Utley, and Technical Secretary Robert E. Kennedy. To the members of the Board of Directors, Assistant to Secretary Jennie Reininga and all the staff we express hearty appreciation and thanks for loyal support throughout the year.

Respectfully submitted,

C. E. Hoyt,
Executive Secretary-Treasurer.

Auditor's Report

CHICAGO, JANUARY 15, 1927

Mr. S. W. Utley, President,
American Foundrymen's Association, Inc.,
Chicago, Ill.

Dear Sir:

I have examined the books of the American Foundrymen's Association, Inc., for the year ending December 31, 1926, and now submit the following statements:

Condensed Balance Sheet

Condensed Statement of Income and Expenses for the year

Detail of expenses for the year

Exhibit A—Balance Sheet, December 31, 1926.

Exhibit B—Balance Sheet—Department of Exhibits—as at December 31, 1926.

Exhibit C—Income and expenses—Department of Exhibits—for the year ending December 31, 1926.

Exhibit D—Balance Sheet—Technical Department—as at December 31, 1926.

Exhibit E—Income and Expenses—Technical Department—for the year ending December 31, 1926.

Schedule I—Special Funds—December 31, 1926.

Schedule II—Award Funds—December 31, 1926.

Schedule III—Surplus—Exhibit and Technical Departments—December 31, 1926.

In my opinion, the Balance Sheet at December 31, 1926, correctly reflects the condition of the Association as at that date.

Respectfully submitted,

ROBERT T. PRITCHARD,
Certified Public Accountant.

AMERICAN FOUNDRYMEN'S ASSOCIATION, INC.

CONDENSED BALANCE SHEET AS AT DECEMBER 31, 1926

ASSETS

Furniture and Fixtures Less Depreciation	$ 665.59
Cash in Bank	12,855.04
Accounts and Notes Receivable	2,616.05
Supplies on hand	1,493.65
	$17,630.33

LIABILITIES

Dues Paid in Advance, etc.	$ 1,501.39
Surplus as at December 31, 1926	$16,128.94

In addition to the above, the Association owns the following investments, the principal or the interest of which is devoted to special purposes.

SPECIAL FUNDS	
Cash in Bank	$ 1,916.63
AWARD FUNDS	
Investments	$21,000.00
Cash in Bank	1,020.65
	$22,020.65
RESERVE FUND	
Investments	$22,119.98
Cash in Bank	503.84
	$22,623.82

AMERICAN FOUNDRYMEN'S ASSOCIATION, INC.

CONDENSED STATEMENT OF INCOME AND EXPENSES FOR THE YEAR ENDING DECEMBER 31, 1926

INCOME		
Dues and Subscriptions	$24,840.74	
Exhibitors' Permits	6,675.00	
Space Rentals, Registrations, etc.	69,034.00	
Interest Earned	379.80	
		$100,929.54
EXPENSES per detail attached		
Technical Department	$31,846.92	
Department of Exhibits	59,445.93	
		91,292.85
Net Income for Year		$ 9,636.69

AMERICAN FOUNDRYMEN'S ASSOCIATION, INC.

Technical Department

Detail of Expenses for the Year 1926

Committee Meeting Expense	$ 2,156.73
Convention Expense	2,698.42
Discount and Exchange	96.37
Dues of Other Associations	30.00
General Expense	47.00
Membership Campaign	442.42
Office Expense	186.46
Postage	2,168,85
Printing	2,029.23
Publications	12,555.72
Rent	699.60
Salaries—Secretary and Assistant	6,500.00
Stenography and Clerical	1,692.45
Telephone and Telegraph	53.88
Traveling Expense	422.99
Depreciation of Furnishings	66.80
Total	$31,846.92

AMERICAN FOUNDRYMEN'S ASSOCIATION, INC.

Department of Exhibits

Detail of Expenses for the Year 1926

EXPENSES	
Advertising	$ 5,771.96
Auditing	235.00
Badges	860.31
Booth work	9,567.24
Building Rental	4,006.34
Cleaning and Repairing	147.93
Committee Traveling Expense	1,144.74
Convention Expense	2,290.65
Exchange	31.69
General Expense	115.94
Installation Expense, Labor	2,361.00
Installation Expense, Superintendent and Assistants	2,349.30
Insurance	192.06
Janitor Service	713.55
Manager and Assistants Traveling Expense	2,000.79
Office Expense	481.64
Postage	582.92
Power—Net Cost	3,711.74
Printing and Stationery	2,535.97
Registration Expense	2,623.01
Office Rent	1,076.50
Salary—Manager	6,000.00
Salary—Executive Secretary	2,500.00
Stenography and Clerical	5,706.50
Telegraph and Telephone	607.40
Watchmen and Doormen	902.25
	$58,516.43
SPECIAL EXPENSES	
Donations:	
A. I. M. E.	$ 250.00
Sand Research—A. F. A. Technical Department	600.00
Depreciation—Furnishings and Equipment	79.50
Total	$59,445.93

Note: Exhibits A to E, and Schedules I, II and III are on file in the Secretary's office and available to members interested.

Annual Address

By the President, A. B. Root, Jr.

The early history of the forming of the American Foundrymen's Association has been so ably covered by other presidents in other addresses and papers on this subject, that these data are available for those interested through the printed proceedings of our association.

However, let me state, that 31 years ago, a group of foundrymen in Philadelphia conceived the idea that through co-operation of those engaged in the industry, a unified policy might be obtained and greater stimulation given to the technical and practical development of the industry. Through the invitation that was sent out by these men, a meeting was held the following year which resulted in the organization of the American Foundrymen's Association.

The principles upon which our association were founded are so sound as to warrant our careful attention and I am taking this opportunity of again stating them as a reminder of our individual obligations to the association and of the position which our association holds in the country today. They are:

First: To conduct research activities which are too extensive or too costly for any except the large organizations to conduct independently.

Second: To act as a clearing house for foundry information and the advanced ideas of practical foundrymen.

Third: To act as a proper representative in matters of industrial relations affecting the industry.

Fourth: To sponsor foundrymen's conventions and exhibits and other meetings of foundrymen having the betterment of the industry as an objective.

The wisdom of our organizers in creating a government of our association which should be self-supporting and which should constantly enlist the services of new workers while retaining the executive direction and advice of our older officers, is evidenced by the enthusiasm with which our activities are conducted. The policy of our association to have a permanent paid secretary and

his staff is a wise one and the association is fortunate in having so able a corps of workers in this capacity.

The success of the association in the technical development of our industry is due in a very large measure to the interest and efforts of the large group of industrial men who have so freely given of their time and their experience for the work of our association.

Our constant efforts are to encourage the membership and interest of the younger men in the industry in order that there may be a constantly increasing source from which to enlist new workers as those who have been in the service for many years take their well earned retirement. It is found that as these younger men gain in experience and the responsibilities in their individual stations that they are inclined to give less time to association activities. My principal message in this connection is to encourage the continuance of the effort of such men on behalf of the association, as it is at that time in their career that they can contribute most to the association and can receive the most satisfaction in return. The association is better prepared today to assist these men in carrying out their association activities through the services of our technical secretary and it is hoped that they will avail themselves of this opportunity so far as possible.

Growth in Membership

Like most enterprises, the means by which an end is attained is changed at intervals to accomplish the desired results and so to increase the usefulness of the association to the largest number of persons engaged in the industry, your directors have proposed, and the members have this year adopted, a revision in the by-laws by which certain conditions individuals may become members in the association without entrance fee and for annual dues of $7.50 a little more than half of what it has cost under the previous plan. Only time will disclose the wisdom of this movement, but already it is evident that this change in entrance conditions is influential, as our secretary advises that since this change in the by-laws was made there has been the largest increase in membership that has taken place in any similar period in our history.

There are enrolled upon our books today a total of 2,070 members, consisting of 400 firm memberships and 1,670 individual memberships, and it is in this latter class that the greatest difference in membership has occurred, the privileges and publications that go with membership thus extending to the actual workers themselves from whom will come the future leaders of our industry.

To stimulate this membership campaign a committee was organized two years ago with the understanding that the vice-president of our association should automatically assume the chairmanship of the membership campaign committee. This committee comprises a representative from each of the states in the union who gathers about him a local committee to assist in the canvass of the foundries in his state. It is due to the work of this committee also that the growth in membership has taken place.

Second International Congress

The plans matured in the minds of our past presidents Clamer and Olson have been crystallized this year in the extending of an invitation to the foundrymen's associations of various countries across the sea and committees were formed who received the delegates in New York and who have arranged for their reception and their visit to the leading industrial concerns in Philadelphia and Buffalo, and who will receive them after this convention in Chicago, Cleveland and Pittsburgh.

That there should be over 100 delegates from these countries is an outstanding event in the history of the foundry industry. Never before has there been such widespread interest manifest in the activities of our profession and the American Foundrymen's Association is honored by the visit of these distinguished men.

I will not briefly outline the work of our various committees during my administration and the activities of our association with allied associations.

Foundry Costs

Under the able leadership of A. E. Hageboeck, the cost committee has held two meetings during the year. It has conducted a

survey of the cost records of foundries. The data thus accumulated indicate that a small percentage of the foundries replying (possibly less than 25 per cent) actually know their costs. The committee therefore decided to continue their campaign with the approval of the board of directors, to educate foundrymen to the need of accurate cost records.

The committee has drawn up and published a set of cost principles and a schedule of cost divisions for the steel, malleable and gray iron foundry groups (nonferrous will be included as gray iron) as a means of continuing its cost education.

It has had a session during the present convention with talks by prominent men on cost work. E. W. McCullough of the United States Chamber of Commerce and R. E. Belt of the American Malleable Casting Association have presented papers on this subject. Because of the interest taken in the weight guessing contest at the convention last year, the committee decided to hold a guessing contest this year on "Production Costs" from patterns representing the four foundry groups, and it is significant that this contest has attracted an equally large amount of interest this year.

Pattern Standardization

The general committee and three sub-committees on pattern equipment standardization have held one joint meeting during the year. A second meeting has been held during this convention. The color chart issued by this committee during the year has been especially well received. Many plants and organizations are adopting the approved color scheme as their standard. The sub-committees on patternmaking and patternmounting have both made certain recommendations in the form of "good recommended practices," although they realize that in each of these fields the circumstances existing in each particular foundry will determine the extent to which the recommendations can be applied.

Since last year, D. M. Avey has taken over the chairmanship of this committee and his proved an active man in the work.

Molding Sand Research

Sub-committees of the general committee on molding sand have been active and each has held one meeting during the year with the exception of the committee on geological surveys, whose work has been carried on at Cornell university, where camples of sand from state geological surveys have been tested. The work of the geological survey committee is practically complete except for some relatively unimportant states from which sand samples have yet to be obtained.

Sub-committee on grading has been working on the developmen of classification standards for grading properties. This report will be made public through the proceedings of the meetings.

The sub-committee on tests has been working on the development of technical and yet practical shop control methods and its report presented to the sand session will be found in the proceedings of the meetings.

The possibilities of the application of these methods has been so clearly demonstrated within the knowledge of the speaker that the committee's recommendations seem to carry a message of vital importance.

The sub-committee on core tests of the sub-committee on grading, has reported on methods of testing core sand and its results will be available from the proceedings of the meeting.

The sub-committee on conservation and reclamation of molding sands has been active. This report likewise will be made a part of the proceedings of the meetings.

Corrosion of Metals

One meeting of the committee on corrosion was held at the American Society for Testing Materials convention, at which time a sub-committee on corrosion was authorized and organized. At this meeting a program of comprehensive research was presented and it is this committee's intention to carry out this research program by co-operation with other corrosion research bodies.

Gray Iron Castings

The committee on gray iron castings has held one meeting at the American Society for Testing Materials convention, at

which time its sub-committee on the study of the addition of scrap to the blast furnace reported progress, and requested authority to proceed with a research program. At this meeting a further sub-committee was authorized to develop a program of research as applied directly to the cast iron field. This sub-committee has since been organized and is developing a program for which research funds will be requested. The work of this committee as now being planned will undoubtedly be one of the most extensive and important pieces of work ever undertaken by the American Foundrymen's Association, and your president recommends the full support of its work by the membership and the board of directors.

Apprentice Training

Because of the interest shown in training boys for foundry work at our convention last year and because of its importance for the future of our industry, the work of this committee has been continued.

A program was arranged by the committee including talks describing apprenticeship training methods in various sections of the country, giving all those interested an opportunity of discussion on the floor on this important subject. The work of the committee in arranging and conducting the apprenticeship molding contest is most commendable, as it has aroused interest in the apprentices and given publicity to the possibilities of apprenticeship training.

Foundry Refractories

A committee under the sponsorship of the American Foundrymen's Association and the American Ceramics Society, organized a little over a year ago, has been extremely active this year in the investigation of refractory problems. Sub-committees have been formed to consider surveys of conditions in the various branches of the industry, simplification and tests.

The reports and recommendations of these sub-committees all will be made available through the proceedings of the meetings this week.

The committees on steel castings, heat treatment of ferrous castings, malleable castings, nonferrous castings, coal and coke

and metallurgy have been in frequent touch with similar committees of the American Society for Testing Materials. In addition to these, the association has had representation on several joint committees.

A safety code committee formed under the procedure of the American Engineering Standards committee, is giving consideration to the following subjects:

Safety code for protection of industrial workers in foundries.

Safety code for machinery for compressing air.

Safety code for exhaust systems.

Safety code for conveyors and conveying machinery.

It is interesting to note that members of the association are interested in the manufacture of, and the use of these appliances and that our representative in each case has been familiar with both phases of these problems.

Program Committee

The program committee this year has presented probably the best program that has ever been prepared for an American Foundrymen's Association convention. Three sessions have been devoted to cast iron research developments. New features this year have been the malleable round table discussion of shop topics which was organized to give malleable foundrymen greater interest in the technical sessions, and the effort on the part of our technical secretary, Robert E. Kennedy, to hold preliminary meetings of the authors of papers at breakfast on the morning preceding their meetings, thus enabling the authors and the chairman of the meeting to consult to bring out the most essential points of their papers.

Other new features have been the symposiums on permanent and long life molds and the temperature determination of nonferrous metals and the session on materials handling, all vital subjects, the presentation of which have aroused such discussion to justify their selection.

The field of nonferrous castings has been very well covered this year by three joint meetings with the Institute of Metals division, and it is interesting to note that the character of the

papers this year has been considerably above the average of previous years.

Speaking generally of all our sessions, it is interesting to note that research papers predominate, yet the practical foundryman has found considerable of interest in the sessions involving discussions of such practical subjects as core binder, materials handling, cupola practice and the round table meeting on nonferrous and malleable practices. The committee therefore is to be congratulated on having combined both phases of the problem in a most satisfactory manner.

Mention should be made that the Exchange Papers from the European foundry organizations have been greater in number this year than ever before. There have been seven such papers presented at our meetings.

I wish to take this opportunity for extending to the officers of the association, to the chairman and members of our several committees, to the Foundry Equipment Manufacturers' Association, to the editors of the several foundry trade journals who through their editorials and other ways have greatly assisted in the preparations for, and the attendance at, this convention, and particularly to Robert E. Crawford, who was responsible for the executive direction of all Detroit committees, my sincere thanks for their most valuable assistance and co-operation, in so ably and cheerfully assisting in the arrangements for and reception of what will probably be regarded in our annuals as the largest and most successful convention and exhibit that has ever been held by the American Foundrymen's Association, during which time it has been my honor and pleasure to serve you in the capacity of president.

Progress of Cost Accounting in Industry

By E. W. McCullough,* Washington, D. C.

It is not my purpose to tire you by tracing the course of cost reckoning in industry step by step from its early beginning for it has existed in business and industry always, being used for the measuring of values and profits.

Nor do I desire to waste time on the rule 'o thumb or so-called estimate methods which were considered good enough in the earlier days when our manufacturing methods were just as crude as our cost accounting. Those good old days are gone forever and the foundry business and every other business must stand or fall on the showing it makes in serving public needs. What commodity is there today, however popular and necessary, that will occupy the same position ten or five or even two years from today with human needs changing as they are. It seems but yesterday that I entered the business of manufacturing farm wagons—the red-wheeled kind, with green box and a landscape painted by hand on its side—it was the only means the farmer had except riding horseback of getting to town, it carried his family to church, his provisions home and his products to market. It was indeed an indispensable necessity even 25 years ago, and at that time Studebaker, Weber, Schuttler and the other 60 or 70 factories were turning out between four to six hundred thousand of them annually and the buggy and carriage makers fully 1,500,000 of horse-drawn vehicles—to say nothing of the horse accessory lines, whips, harness, blankets, horse shoes and the like.

Today these lines have passed out to make room for the rapid moving motor driven vehicle and even the wayside smithy is replaced by a repairing garage.

We no longer cut and store ice against the hot days of summer. Even ice making by great refrigerating machines is declining rapidly and with electricity and chemicals we produce cooled

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air instead, forcing vast amounts of capital formerly employed in the ice business into other channels and an army of men into other employment, which fortunately we have for them.

I could go on and enumerate a hundred or more lines this evolution has wiped out and lines without number which have changed in materials, construction and form; in fact, there are practically none which remain unchanged and all are in a constant state of reform and improvement. Progress has always promoted changes but never have we moved at so rapid a rate as now—the manufacturer who does not keep every department of his business up-to-date and his management on its toes will share Dempsey's fate.

It is up to you who are engineers, metallurgists, superintendents, foremen and technical men in general, who are here not only to see these fine displays of improved foundry equipment but to discuss your problems of production, not to stop there but to take into account every factor affecting the success and future of your business. You cannot afford to overlook anything which will give you an advantage and keep your line to the front.

Today competition is stronger than ever between competing lines. In road building the associations representing the makers of cement, asphalt and paving brick are spending large sums in courting public favor. In textiles the war between silk, cotton, rayon and wool is on.

Nor are you being overlooked in metal utilization for gray iron, cast steel, malleable, wrought steel, aluminum and several alloys are in the ring fighting for recognition as "the best and the cheapest." Industry in general is, I believe, striving to work out the ideal enunciated for manufacturers by a business man—Julius H. Barnes, former president of the chamber of commerce of the United States, who said: "I conceive it to be our duty to take the natural resources of our country, yea of the world and convert them, at the lowest cost, into the greatest number of useful commodities, to the end that every one may have his share not only of the necessaries of life but its luxuries as well."

So much for the situation in industry as it appears today as our problem.

What Is Cost Accounting?

What is the secret of producing commodities in any quantity at the lowest cost?

The answer is "initiative and cost accounting."

What is cost accounting?

My definition is—

> "It is science or process of tracing every dollar of expenditure in business and industry to its most economic use, in the determination of values."

At the time Edward N. Hurley, then chairman of the federal trade commission, made the bold statement that "according to his observation fully 80 per cent of the manufacturers of the country did not know what their costs were," it produced a shock and was by some considered an insult, but it also brought about an awakening, which I believe helped us on our way to the present progress in cost accounting.

Adding together materials and labor which can be definitely measured and estimating the overhead or burden is not modern cost accounting. Nothing may be guessed at or estimated—it must all be measured accurately. Overhead which in many lines is today by far the more important element in costs cannot be treated with indifference as in the past.

Again, real cost accounting is not writing operating history. A cost system which in its operation fails to find and eliminate waste and expedite production should not be called a cost system today. I am not unaware of some of the conditions in foundry work which make it more difficult than in some lines to operate a cost system and secure the co-operation of the shop men, but I know of none which create an impossible situation; in fact, you are to hear later in this program from two able speakers who are prepared to tell you how it is being done. When everyone having a part in using a cost system realizes that in co-operating he is both advancing his own interests and that of the business in which he is engaged difficulties disappear.

Uniform Cost Accounting

In every mention I have made of cost accounting I am referring to uniform cost accounting, which is the only kind which

should be used by a group of manufacturers making the same commodity. By uniformity I mean uniform principles and using uniform methods whereby all in the same line include the same elements in their cost calculations—this permits cost comparisons between competitors or the members of an association and has been pronounced legal if the purpose or results of such comparison are not used unlawfully.

The adoption of uniform methods does not mean the scrapping of individual systems now in use but merely bringing them into harmony with the principles adopted which accomplishes uniformity.

Factors Which Have Delayed Progress in Cost Accounting

I desire now to touch upon three other ideas which have hindered the adoption of good cost accounting:

First: That a large increase in clerical help would be necessary.

Second: That the workmen in the industry could not be induced to make records nor co-operate with others doing so.

Third: That the cost of operating a system would be too great.

Perhaps the best answer I can return to them all is that few, if any, of the largest or best equipped foundries are without cost systems today and they could not run a day without them except at a loss.

However, touching on the point of additional clerical help—there are but few instances of record where large additions were necessary, but as in every worth-while operation involving efficiency, the work should be in charge of someone who understands it, but aside from this there are few organizations in which the clerical force has its time so fully occupied that it could not take care of the small amount additional involved in these cost operations, especially when they have been standardized and made an orderly procedure.

Answering the second question, which is by far the more important, that the workmen are not of a character from which

to secure proper co-operation. This, I believe to be a slander upon the intelligence of our American labor, for if there is one country in the world where initiative and co-operation on the part of the workmen have proven a large factor in the country's industrial progress, it is here. Show the American workman where he will secure a fair division of the gains or economies made and he will respond. The making of daily records of production by the individual worker has become such a common practice and the use of mechanical recording devices so general that it is hardly necessary to go into the matter further, for when the workman realizes that he will have an opportunity of making his own records, which no one can change, instead of objecting to it will insist upon his right to do so.

And finally answering the third objection that the cost of operating a system would be too great. This would stand on the same grounds as the installation of automatic, or labor-saving machinery. In lines where competition is intense it simply could not be dispersed with.

What Others Have Said

In preparing to address you I have had the advantage of a very comprehensive file on cost accounting, which we maintain in the chamber, which contains a vast amount of information including copies not only of papers which have been written from time to time for your industry but addresses which have been delivered in the past before your association. In fact, this subject has been so much discussed and so intelligently dealt with that surely the time is ripe for definite action!

No doubt many of you have read the excellent paper entitled, "Cost Finding in a Foundry," presented by W. J. Corbett, of Chicago, at your Milwaukee meeting in 1924, in which the following good logic and sound sense is set up:

> "A uniform method of cost finding in an industry is especially advantageous for establishing marketing policies. Vast differences in the costs of making specific castings at various foundries are usually due more to the use of different methods of cost finding than to methods of production or other economic conditions."

Again, he summarizes the following points relative to the uses of an effective cost system:

"1.—To ascertain the cost of making castings.

2.—To measure the efficiency of labor.

3.—To ascertain the consumption of materials and supplies.

4.—To serve as a guide for correcting faulty operating methods.

5.—To provide the stimulus of chronological comparative records.

6.—To furnish data for intelligent merchandising."

Then, dealing with the functions of a cost system, he suggests:

> "It must provide data for the preparation of financial statements; it must serve the management in controlling operations; and it must be a means for preventing a serious loss in meeting competition."

I am sure that we can agree that this reasoning is simple, common-sense, and sound.

Quoting from another interesting, comprehensive paper on the "Advantages of a Foundry Cost System," Mr. Robert E. Belt, of Cleveland, published in the *Iron Age* in 1921, several points made in it are outstanding and are fundamentally sound. He says:

> "No matter how modern and improved may be the technical end of the business its successful conduct is not assured unless the cost of the various classes of product is known and the product disposed of at a figure in excess of cost."

And again quoting him:

> "Experience has demonstrated over and over that in the production of castings it is not safe to base a selling price on an average cost. In a jobbing foundry, the cost of the work of no two customers is the same; the cost of no two patterns is the same. With almost every order, conditions vary, and the cost of production always varies with the conditions. The variations in cost should be known, studied, analyzed and watched."

Still further, he states:

> "The foundryman who is fortified with an accurate knowledge of his costs of production always has an advantage. Every foundryman should know his costs regardless of cost methods. It were far better, however, if each distinct branch of the industry is to adopt uniform methods, as unfortunately, differences in accounting methods do produce different results."

Need for Action in Establishing Uniform Methods

I am wondering if most of you have not sometime ago, not only realized and appreciated the value of uniform cost accounting, but have wished that steps might be taken in the industry to produce a real, practical uniform system which I may say, today is a reality in a number of industrial lines which I will mention later on.

However, it is one thing to be convinced that a certain action should be taken, but quite another to determine to act and put such desires into execution. In our cost accounting work, after watching for several years the progress being made in cost accounting lines and the testing of systems and methods in a number of industries, we reached the conclusion that the place to build a uniform cost system was within the industry desiring it. *First,* because those in the industry, particularly the accountants and cost men, know and understand its problems better than any others. *Second,* in the building of a uniform system within the industry, its operations would involve the establishment of confidence and co-operation of those who would make practical use of it. And, *third,* and very important, is the fact that a cost system is never complete, but is in need of constant adjustment to meet the variations and changes which are occurring constantly in labor, equipment and overheads.

We have no quarrel with the cost accounting profession, which today contains many good and efficient men, but we feel that the development of the cost system should be the job of the industry and that the function of the professional accountant should be a supervisory relation rather than a contractual one. The best argument we can present in support of this is that no

business is learned in a day nor can it be fully comprehended or understood in a brief survey by any mind, no matter how expert. The problems noted by an observer surveying the plant one week, may change radically the next.

Plan of Procedure

In following our conclusions and working them out in a practical way we have set up a very simple plan of established principles and methods whereby any industry may build its own uniform cost system and we have published three booklets which set forth the steps which may be taken to accomplish it.

The *first* deals with the thorough selling of the industry that such a cost system is necessarily necessary and desirable. The *second* with the creation of a cost committee, made up not altogether of executives, but of comptrollers and cost men who daily handle or have contact with the development of costs.

Beginning with these two fundamentals the development and working of the plan proceeds just as rapidly or as leisurely as the industry may determine. When the committee and the accountants of the industry have developed and are ready to present the cost manual it has been invariably found that the greater number in the industry have been thoroughly sold as to its advantages and the installation of the system is a mere matter of routine.

It has been our experience that with systems which have been developed for an industry and afterwards the effort has been made to sell it to them and have it installed, that such plans have experienced the greatest difficulty and a very large number have utterly failed of accomplishment.

What Other Industries Have Done

Appreciating that you would desire to know whether the plan I have suggested would work out, or had been worked out practically in industry, I shall mention a few organizations which have built, installed and are using such uniform systems.

The International Association of Milk Dealers, composed of the folks who receive raw milk from the farmer, sterilize or pasteurize it, then bottle and deliver it to the consumer, has built

such a system in the face of almost unsurmountable obstacles, because of their membership being scattered almost entirely throughout the United States and Canada as well. Their membership is also composed of the very smallest concerns as well as the very largest and the profits per unit, as you may well imagine, are exceedingly small, sometimes the fraction of a cent—consequently, their system of processing and the cost of delivery under varying conditions requires exceedingly fine calculations. As an industry which has grown tremendously since milk has become one of our chief food products, the association took a very broad view of the necessity for having a uniform cost system and not only appropriated liberally for its development, but has supported it consistently throughout its stages of development.

At a meeting which received the completed manual, a member commented on what seemed to be the large cost of the work, but his comment brought forth a reply from one of the leaders of the industry who had given generously of both time and money. His rejoinder was: "In the building of this cost system the members of our industry have been brought more closely together than ever before—groups of accounting and operating men have met here and there over the country and have not only done their part toward the building of this system but have exchanged information on other matters so that today the relations between the members of our industry are better than they have been at any other time. I should regard it proper to charge one-fourth of this expenditure to the cost system and seventy-five per cent of it to the promotion of better trade relations, and credit against both charges benefits to the industry far in excess of both charges."

The National Association of Ice Cream Manufacturers, representing an industry which has suddenly sprung into great public favor, has followed the milk people in also developing a uniform cost system and is now engaged in making their installations.

More than one hundred and twenty-five lines having trade associations have adopted cost systems, among them the following:

American Drop Forging Institute
American Malleable Castings Association
American Photo Engravers Association
Associated Knit Underwear Manufacturers

The Paper Industry
The Folding Box, Label and Lithographing Industry
Glazed and Fancy Paper Manufacturers Association
Knitted Outer-Wear Manufacturers Association
Laundry-owners National Association
Millwork Cost Association
National Association of Finishers of Cotton Fabrics
National Macaroni Manufacturers Association
National Paper Box Manufacturers Association
National Tent and Awning Association
National Varnish Association
Newsprint Service Bureau
Paint Manufacturers Association
Plywood Manufacturers Association
Portland Cement Association
Printing Ink Manufacturers Association
Rubber Association of America
Tanners Council
United Typothetae

In this list are several lines to which it is infinitely more difficult to apply uniform cost accounting than your own and also several instances where metal working industries closely allied to your own have used such systems and are benefiting by their use today—this is clearly proof of the pudding.

Labor and Cost Accounting

If more proof were necessary to emphasize the need of using the best cost methods today it is to be found in the desirability of maintaining the present status of our labor relations. We are paying high wages and generally speaking, getting high production. Formerly the stress of competition forcing lower prices generally brought a reduction in wages which in turn brought about lessened buying. Today we are pursuing a wiser course and wage reductions occur only after all other economies have been made, but to do this intelligently the cost of every factor in production must be measured on the basis of cost. Wage disputes may often be settled when a careful review of costs reveals the fact that

the largest measure of labor cost has been put into the commodity that its selling price will permit and to add any increase will result in a trade loss in which both employer and employee will suffer.

Summary

Permit me to briefly sum up my conclusions reached from reasoning from the bases of my presentation to you:

1.—That for success, profit and continuation of the industry the best cost accounting is necessary.

2.—That individual cost accounting is good, but in a competitive line uniform cost accounting is better and promotes intelligent competition.

3.—That the foundry industry, because of the frequent presentation of costs at many conventions and other meetings by men of the industry and others who know, needs no further proof to guide its judgment.

4.—That the present is most opportune for beginning the construction of a uniform cost system, but requires the concurrence of the executives and those in charge of production.

I am pleased to place at your disposal the services of both my department and the Chamber of Commerce of the United States of America, whom I represent, for use in every helpful way.

Discussion

Chairman A. E. Hageboeck: I think Mr. McCullough has done *three things,* he has given us a *vivid picture of our industry* today, he has suggested *a remedy,* and then he has explained how we can follow through and *apply that remedy.*

I want to know how many shop superintendents we have here this afternoon. At least 15. Very good. I knew there were several, but I didn't have any idea there were that many.

Now there is another point that to my mind is vital, you have to sell your cost program first to the big boss. If you haven't the big boss with you on it you won't get anywhere. But equally important is the little boss. The little boss is very important. I mean the foundry foreman, the man Mr. McCullough talked of, and, of course, the man

right on the job, the direct laborer, whoever he might be. We had a man talk to our Quad-Cities Foundryman's Association at Moline, Illinois, last year and he dwelt at some length with this phase of the little boss. He said, "It is your foundry foreman who makes the costs. Your office transmits the costs and gives it back to you. It comes in, in the shape of time tickets and the office rearranges it. Too many men in the shop think the office makes the costs. If we can get that across to the men, that they themselves make the costs, it will be a great step forward. The trouble is, a man who doesn't know about the cost system thinks right away in terms of a whole office full of clerks.

We have another paper by one who has been referred to by Mr. McCullough. This gentleman added greatly to our discussion at Syracuse last year. I am very glad to be able to introduce to you a man who has prepared a paper and who has some slides on foundry cost accounting, a practical system for the small foundry, Robert E. Belt, Secretary of the American Malleable Castings Association of Cleveland.

Chairman Hageboeck: I would like to call attention to the fact that Mr. McCullough has offered the services of the United States Chamber of Commerce in connection with any program that the A. F. A. propose to work out. The counsel of this organization should be of distinct advantages and it is up to us to avail ourselves of this opportunity.

At a recent meeting of the cost committee of the A. F. A. we were fortunate in having present practically all of the members of our committee, including three gentlemen representing three distinct branches of the foundry industry, represented by the following:

W. J. Corbett, representing the steel industry.

R. E. Belt, representing the malleable industry.

E. T. Runge, representing the gray iron and non-ferrous industry.

At this meeting it was proposed to see what could be done as a first step in establishing a uniform method of cost accounting in the foundry industry. The result of this effort is what we have presented at this session known as exhibit No. 1, "Standard Basic Department" for uniform cost accounting, as recommended by the cost committee of the American Foundrymen's Association.

Your comment and constructive criticism on this outline is solicited. The thought the committee had in mind was to show that it was possible to record on a single piece of paper, the basic departments necessary for establishing cost system in the various branches of the industry, and that as a matter of fact, these basic departments were practically identical for the various branches—varying only in detail being alike in principle.

Fred Erb: In our work on the Cost Committee it seemed as though every one had some sort of cost idea, but when we carefully examined them they were about all the same. We now have on the committee three men, Mr. Runge, Mr. Belt and Mr. Corbett representing the gray iron, the malleable iron and the steel groups respectively. These definitions

of standard basic departments we have here are really the result of these three gentlemen getting together and putting into simple words the basis of a cost system, and we feel that this is, you might call it exhibit No. 1, step No. 1. There is a good deal more to be accomplished. And I feel the Cost Committee is going to do the most valuable work that has been done by any committee of the American Foundrymen's Association. The sand group, of course, has been one of the leading groups; but the support we have had here and the attendance shows that there is keen interest in costs. And this interest wants to be kept up, and each individual here can help in keeping it up.

CHAIRMAN A. E. HAGEBOECK: Thank you for those remarks, Mr. Erb. That is just the thought we want, for we are right at the point where we have to go ahead or quit.

In that connection, I would like to have, if we could, some comments on the many points Mr. McCullough brought up. I think you have covered the field so completely, Mr. McCullough that there isn't much left to talk about.

MEMBER: Is it your intention to go ahead on this plan?

CHAIRMAN HAGEBOECK: I say yes. Unfortunately our Association, a number of years ago, went into a very elaborate system for cost accounting and endeavored to get this adopted by the foundries but this system was not well received, and as a result the Board of Directors spent a lot of money and did not get results. For this reason it has been rather difficult to interest the Board in any cost accounting that would involve first—the expenditure of money and second—that would attempt to set up standards as recommendations from the A. F. A.

J. L. CARTER: I certainly think this matter of uniform cost systems is one of the most important things confronting the industry, and it seems to me the American Foundrymen's Association is the proper organization to handle it. I personally am very much in favor of going ahead and pushing the work of the Cost Committee just as strongly as possible. There is just one thing I want to call your attention to, I think the one task of pushing the uniform cost system is up to the local Foundrymen's Associations. Mr. Runge has done a great deal of that work and I know he has been responsible for starting five or six, probably more, uniform cost systems in certain localities. We have one in Newark we have been using for four years and it has improved conditions a great deal. One part of the work of this committee has been to encourage, through local committees, the getting together of the foundries, and I think that that is a very important phase of the work. And if someone can be delegated to go to the districts and co-operate with them in starting such a medium of local foundrymen getting together and talking the thing over, you can arrive at a working system much better.

Mr. Francis: It seems to me that you have the malleable, steel and cast iron industries well covered on this committee, but from Mr. Belt's paper I notice you have pretty well left off the non-ferrous foundrymen. I am in a position to have reason to check up a number of the small foundries up in Canada, the non-ferrous foundries, and it is surprising to me how many of those are operating just in the balance, the least little move one way or the other and they will go under. Now if the non-ferrous foundrymen could get together or if the committee could do something to stimulate uniform cost keeping among the non-ferrous foundrymen, I for one would like to do all I could.

I think the non-ferrous casting industry presents different problems than what you run up against in iron. In melting alone, perhaps in the manufacture of one casting, you melt one hundred pounds of metal to get only 40 pounds of casting, and the cost is more than in another case an 80 pound casting will be produced from 100 pounds of metal. I think their position is due to working too close to the red line mark.

Chairman A. E. Hageboeck: We included in our last column, if you please, gray iron and non-ferrous metal. So we haven't omitted non-ferrous metals altogether. Mr. Belt's paper was primarily for the gray iron foundry.

Now to summarize as I see it Mr. McCullough, in your opinion it is the function of the American Foundrymen's Association to be a clearing house for the foundry industries in matters of a uniform cost accounting. The thought being that the A. F. A. would recommend the principles, leaving the details to be worked out by the various branches according to their peculiar needs.

E. W. McCullough: Yes.

J. L. Carter: Isn't the steel association taking care of their end? Isn't it a fact that we need gray iron costs primarily?

Chairman A. E. Hageboeck: We do, absolutely. That is true. The other fellow has his job done, we have just started; maybe we haven't even started.

Mr. Twichell: In regard to Mr. Carter's remarks about working a uniform cost system through local foundrymen's associations, it has been our experience in local associations that in labor troubles, in our section at least, the members have been unable to get together, so I would say that I think the American Foundrymen's Association would be the one to handle it direct.

J. L. Carter: A point I want to emphasize is that the foundrymen's associations have all gone on the rocks when it comes to labor troubles. And I would just like to make the suggestion that if the local foundrymen's association would take up uniform cost work as one of the basic

objects in getting the foundrymen together rather than labor troubles, I think they would progress more rapidly.

Mr. Ziegler: We had just about the same experience as the gentlemen from the Hamilton organization, we formed a couple of times and broke again over the same thing. But I believe that the American Foundrymen's Association should push the idea of uniform cost systems as the outstanding thing for which the Association was formed and leave the labor and price questions out entirely. Let your local associations be formed for the purpose of getting a uniform cost system. We have a cost system that is perhaps right and perhaps wrong, but it has done a good deal. I think Mr. Carter's idea is all right. I think it can be done if we leave out prices and labor. And I think it is best done through local organizations with the American Foundrymen's Association pushing it.

J. L. Carter: I would like to make a resolution that it be the sense of this meeting that the American Foundrymen's Association take up cost work vigorously and push forward the work of the committee as fast as possible; and part of the work of the committee should be to urge the adoption by local community foundrymen's associations of a uniform cost system to be adapted to their own needs in conference with the American Foundrymen's Association Cost Committee.

Chairman A. E. Hageboeck: Your idea is then, that it is the sense of this meeting that it is the function of the American Foundrymen's Association to co-ordinate a uniform cost method for the various branches of the foundry industry and that an effort of determined nature be started to have this recommended method of cost keeping adopted through whatever channels seems expedient. Thus calling attention to the fact that local groups seems to be one method and it is our job to find other ways and means to accomplish the purpose.

E. W. McCullough: "I don't want to frame your resolution for you but it seems to me that it should cover the ground somewhat in this manner:

"RESOLVED, That we approve the recommendation of the Cost Committee that the American Foundrymen's Association develop a uniform cost system; and

"Second, that when the system is produced and approved it be recommended for the use of all members, including the various groups."

I feel that the first thing to be done is the harmonizing of the present existing cost systems, especially those that are being used for steel, malleable iron and gray iron. The principles can be harmonized and you can have the underlying principles the same for the entire foundry business. In the application of this uniform system to gray iron, malleable iron and steel there may be some details of difference, but when the

steel men and the malleable iron men and the gray iron men figure on the same basic principles, adding such details as come into their particular division you have a uniformity which will be invaluable in bringing about better conditions in the foundry business. This has been done in the milk and also the ice cream business along just such lines.

CHAIRMAN A. E. HAGEBOECK: I take it the sense of this meeting is that we proceed to recommend a uniform cost system for the various branches in the industry and that we proceed to encourage the adoption of this method in the industry through the group plan or any other plan that presents itself that will seem to accomplish the purpose.

Now is that or is it not the opinion of those members present?

J. L. CARTER: I make such a motion.

The motion was seconded.

CHAIRMAN HAGEBOECK: It has been moved and seconded. Is there any discussion?

A MEMBER: I am highly in favor of forming local groups, and I understand the American Foundrymen's Association is going to head up this thing and form groups and let them carry it out. Now the smaller foundries that are hardest hit, you will get them in your local groups, whereas if it is left just as it stands now, with the American Foundrymen's Association approving it, the smaller companies will know nothing of it. Hadn't there ought to be some means of getting the word to the smaller foundries and try to get them into the local groups?

CHAIRMAN A. E. HAGEBOECK: I tried to include that by saying it was the sense of this meeting that the American Foundrymen's Association develop a uniform cost method and that it proceed to encourage the forming of the foundrymen into groups to take up this matter of cost. Will that cover your suggestions?

MEMBER: Yes!

CHAIRMAN A. E. HAGEBOECK: The sense of the meeting is that it is the function of the American Foundrymen's Association to proceed and develop a uniform cost system for the industry.

And further, it is resolved that it is the sense of this meeting that the Committee proceed to interest the foundrymen in their costs, preferably through the group method, on a plan to be developed by the Committee, with the thought in mind that the groups where it has been tried are successful.

All those in favor say "AYE." Those opposed "NO." The motion is carried.

Foundry Cost Accounting

Cost System for a Small Foundry

By Robert E. Belt*

The foundry industry, due in part to the character of the product and in part to commercial practices, is a highly competitive one. To market castings, therefore, without a knowledge of what it costs to produce them is hazardous. It is entirely safe to say, based on the observations and experiences of those coming in contact with foundry office practices, that at least two-thirds of the jobbing foundries of the country do not know where they are making money, if they happen to be making some, or where they are losing money, and to what extent, when their profit and loss account shows in red. Evidently, therefore, at least two-thirds of the jobbing foundries of the country do not know when they quote on work whether or not they can reasonably expect a profit on it should they receive the order. They do not know definitely on what lines or on what kind of work they have been able to make a profit in the past. In the absence of an adequate knowledge of costs, they have no experience to guide them and their balance sheet at the end of the year usually reflects the results.

My work in the foundry industry the past several years has brought me in touch with the profits of a great many foundries, and I can say without reservation that the companies at the present time and in the past that know and have known definitely their profitable and their unprofitable work are the companies that are making and have made the best profit showing.

Foundry Accounting Not Difficult

To determine the production cost of a casting with reasonable accuracy is not difficult or expensive. Many foundrymen, however, conclude, for some reason, that foundry accounting is both intricate and expensive. The reason for this belief, I think, is that in many offices a great deal of effort is wasted; records are not properly related; the cost department, the time department

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and the bookkeeping department are performing separate operations and making duplicate entries. This is the result of the designing of records at different times to supply certain information which may then be needed without taking into account other records which are then being kept, or of considering the relation of the one record to another.

The Cost Plan

An accounting plan should be designed with the same precision as is a piece of machinery, namely, to accomplish, as a whole, a certain thing, and every part of an accounting plan should function just as efficiently as do the parts of any piece of your foundry machinery. Unless records are related and the needed information gathered efficiently there is the appearance, and rightly so, of red tape and questionable benefits. The primary purpose of this paper is to demonstrate a method of gathering foundry costs where the records are related and which experience has proven to be both practical and efficient.

It is not claimed that the procedure outlined is exactly suitable to all foundries without some adaptation. The claim is made, however, that with minor adaptations, the principles, the forms, the classification of accounts, the methods of distributing overhead expense, and the procedure in determining the cost of individual patterns of castings can be used in a satisfactory manner by practically every small and medium size gray iron foundry.

The cost procedure herein set forth is designed primarily for gray iron foundries of the smaller size, as under this head there is a larger proportion of foundries in need of more dependable information than of any other class. For the larger gray iron foundries some modification of the cost structure is advisable to provide more detail information and somewhat more accurate costs. The fundamental principles, however, are unchanged regardless of the size of the operations, the principal difference being that of a greater number of cost accounts or subdivisions for the large foundry and of a departmental distribution of fixed plant charges. Furthermore, in some of the larger foundries the costs of certain operations such as cleaning, chipping and grinding can be recorded separately whereas in the smaller foundries this is not generally practicable.

Classification of Cost Accounts

The first step in a cost structure is an orderly and logical classification of cost accounts, the primary cost divisions following as nearly as possible the sequence of the manufacturing process.

In the classification of cost accounts, Table I, both account numbers and account names are shown. The system of numbering the accounts is such that the number identifies both the department and the nature of the expense. In each instance, the first number identifies the department and the second number the nature of the expense.

The primary cost divisions are:

Metal
Melting
Molding
Coremaking
Cleaning, Finishing and Shipping
Fixed Plant Charges
Administrative and Selling

Metal

The metal accounts constitute the first primary cost division and embrace the cost value of metal of all kinds charged into the cupola.

Melting

The melting department is that part of the plant in which the iron is melted. The departmental operations for cost determining purposes begin with the assembling of the pig iron, scrap and coke at the places of storage and end with the delivery of the molten metal into the ladle at the spout of the cupola.

Molding

The molding department of a foundry is that part of the plant in which the molds are made, including the operations of such shops as serve the molders, such as carpenter shop and molding equipment repair shop. The departmental operations for cost determining purposes comprise in general the operations of assembling the molding materials and supplies, of making the

Table 1

CLASSIFICATION OF COST ACCOUNTS

Metal:
- 10–1 Pig Iron
- 10–2 Purchased Cast Iron Scrap
- 10–3 Home Sprue and Scrap
- 10–4 Steel Scrap
- 10–5 Alloys

Melting Department:
- 22 Indirect Labor
- 23 Fuel
- 24 Supplies and Tools
- 25 Repair Labor and Materials
- 26 Cupola Relining Expense

Molding Department:
- 31 Direct Labor—Molders' Payroll
- 32 Indirect Labor
- 34 Supplies and Tools
- 35 Repair Labor and Materials

Coremaking Department:
- 41 Direct Labor—Coremakers' Payroll
- 42 Indirect Labor
- 43 Fuel
- 44 Supplies and Tools
- 45 Repair Labor and Materials

Cleaning, Finishing and Shipping Department:
- 52 Indirect Labor
- 54 Supplies and Tools
- 55 Repair Labor and Materials

Fixed Plant Charges:
- 60–1 Power, Heat and Light
- 60–2 Fire Insurance
- 60–3 Liability Insurance
- 60–4 Taxes
- 60–5 Depreciation
- 60–6 Supt., General Foreman, and Misc. Yard Labor
- 60–7 Miscellaneous Plant Expense

Drayage

Returned Castings and Allowances

Administrative and Selling Expense:
- 70–1 Office Salaries
- 70–2 Office Expense
- 70–3 General Expense

DEFINITION OF COST ACCOUNTS

Metal

10–1 Pig Iron:
To include the cost of all pig iron used, including freight, and labor in unloading.

10–2 Purchased Cast Iron Scrap:
To include the cost of all purchased cast iron scrap used, including freight, and labor in unloading.

10–3 Home Sprue and Scrap:
To include the value of all defective castings, sprue, gates, runners, over-iron and spill used.

10–4 Steel Scrap:
To include the cost of all steel scrap used, including freight, and labor in unloading.

10–5 Alloys:
To include the cost of all alloys used, such as ferro-manganese, ferro-silicon, etc., including freight and labor in unloading.

Melting Department

22 Indirect Labor:
To include all labor identified with the melting of the iron, such as, handling and conveying iron and fuel to the cupola, charging, daily patching of cupolas, craneman, slag mill labor, blacksmith labor in making and repairing pokers, bars, etc., chemist, foreman.

(Continued on next page)

Table 1

(Continued)

23 **Fuel:**

To include the cost of all melting fuel used, including freight, and labor in unloading.

24 **Supplies and Tools:**

To include the cost of all supplies, such as flux, wood, brick, blocks, and fire clay used for the daily patching of the cupolas.

25 **Repair Labor and Materials:**

To include the cost of all labor and material used in connection with the upkeep and maintenance of the cupolas and their equipment, exclusive of labor and material for daily patching which are chargeable to accounts 22 and 24.

26 **Cupola Relining Expense:**

To include the cost of all labor and material used in connection with the periodical relining of the cupolas.

Molding Department

31 **Direct Labor:**

To include all labor of molders and helpers in putting up molds; operating molding machines, green sand core work, and pouring, when done by molders or helpers.

32 **Indirect Labor:**

To include all labor in the foundry other than that of putting up molds, such as, wheeling flasks and sand, wetting sand, cutting and tempering sand, mixing sand and facing, delivering metal to molders' floors, but not including pouring when done by molders or helpers, shifting mold weights, jackets, or cases, returning patterns to storage, relining foundry ladles, dumping and shaking out molds, breaking gates, gathering up scrap, conveying castings to cleaning department, carpenter labor in the making and repairing of flasks, jackets, bottom boards, etc., foreman and clerks, including pattern clerk.

34 **Supplies and Tools:**

To include the cost of all supplies and small tools used in the foundry, such as molding sand, facing, parting, chills, chaplets, flask lumber, molders' tools, riddles, bellows, brooms, brushes, shoves, wood for drying ladles, etc.

35 **Repair Labor and Materials:**

To include the cost of all labor and materials used in connection with the upkeep and maintenance of the foundry equipment, such as repairs to molding machines and molding benches, molders' tools, etc.

Coremaking Department

41 **Direct Labor:**

To include all labor of coremakers and helpers in making and assembling cores, both piece and day work, including green sand coremaking when made in the core room.

42 **Indirect Labor:**

To include all core room labor other than that of actually making cores, such as oven tenders, pasters, when work is not chargeable directly to the job, loaders, carriers and board collectors, inspectors, counter and tally boys, cleaners, sand mixers and rosin grinders, coke wheelers, pulverizing old cores, core plate collectors, sand wheelers, dispatchers, painters, assorters, wire cutters and straighteners, delivering cores to foundry foreman and clerks.

43 **Fuel:**

To include the cost of all core fuel used including freight, and labor in unloading.

44 **Supplies and Tools:**

To include the cost of all supplies and small tools used in the core room, such as core sand, core oil, rosin and pitch, compounds, wire, rods, core plates, coremakers' and laborers' tools, etc.

45 **Repair Labor and Materials:**

To include the cost of all labor and materials used in connection with the upkeep and maintenance of core room equipment, such as repairs of ovens, racks, trays, etc.

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Table 1

(Concluded)

Cleaning, Finishing and Shipping Department

52 **Indirect Labor:**
To include all labor of cleaning, finishing and shipping, such as loading and unloading mills, operating sand-blast barrels, tables, and hose, chipping, grinding, inspecting, sorting, packing, weighing, trucking, loading, cleaning up department, foreman.

54 **Supplies and Tools:**
To include the cost of all supplies and small tools used in the cleaning, finishing and shipping department, such as sand-blast sand, air hose, stars, jacks, emery wheels, chipping hammers and other small tools, sacks, twine, etc.

55 **Repair Labor and Materials:**
To include the cost of all labor and materials used in connection with the upkeep and maintenance of all cleaning, chipping and grinding equipment, such as repairs to mills, sand-blast apparatus, dust arresters, chippers, grinders, etc.

Fixed Plant Charges

60–1 Power, Heat and Light:
To include the cost of all purchased current; all costs of labor, materials, supplies and expense in producing power; labor and materials in repairing boiler and engine room equipment, including air compressors, accumulators, pumps, generators, transformers, etc., located in engine room; boiler insurance, etc.

60–2 Fire Insurance:
To include all premiums for fire insurance and all costs of fire protection.
Charge the account monthly and credit "Prepaid Fire Insurance" account, the entry being one-twelfth of the annual expense.

60–3 Liability Insurance:
To include monthly premiums on employer's liability insurance policies.
Charge the account monthly and credit "Prepaid Liability Insurance" account, the entry being one-twelfth of the annual expense.

60–4 Taxes:
To include all tax payments and assessments on both real and personal property.
Charge the account monthly and credit "Accrued Taxes" account, the entry being one-twelfth of the annual expense.

60–5 Depreciation:
To include charges to cover the deterioration in the value of the buildings and equipment due to wear and tear and obsolescence.
Charge the account monthly and credit "Plant and Equipment Depreciation Reserve" accounts, the basis being one-twelfth of the annual expense.

60–6 Supt., General Foreman, and Misc. Yard Labor:
To include the salary of the superintendent, general foreman and all miscellaneous yard labor.

60–7 Misc. Plant Expense:
To include all forms of miscellaneous plant expense of a general nature not included elsewhere, such as water, rent, employes' welfare, medical and hospital, personal injury payments when not covered by liability insurance, etc.

Drayage:
To include the cost of delivering castings to depots and to city customers, and incidental drayage on miscellaneous small items which cannot conveniently be charged to the cost of the commodity.

Returned Castings and Allowances:
To include the invoice price less scrap value of defective castings returned by customers and allowances to customers because of defective castings. Defective castings are those which cannot be reclaimed.

Administrative and Selling Expense

70–1 Office Salaries:
To include the salaries of clerks, salesmen, and of all general officers.

70–2 Office Expense:
To include all expense incidental to the office, other than salaries.

70–3 General Expense:
To include all forms of miscellaneous expense of a general nature that cannot be included elsewhere, such as membership dues, donations, etc., not, however, to include federal income and profits taxes, which are not cost items.

molds, of pouring the molds, of breaking off the gates and heads from the castings, the return of the sprue and scrap to the cupola for remelt, and the delivery of the castings to the cleaning department.

Coremaking

The coremaking department is that part of the foundry in which the cores are molded, baked, and at times temporarily stored. The departmental operations for cost determining purposes comprise the operations of assembling the materials entering into core sand mixtures, of molding the cores, of baking them and of delivering the finished cores to the Molding Department.

Cleaning, Finishing and Shipping

In the larger gray iron foundries there are separate operations and sometimes distinct departments of cleaning, finishing and shipping and accordingly separate departmental operations for cost determining purposes should be observed. In the smaller foundries, however, these three operations are generally so mixed that cost divisions are not practicable. Accordingly, these operations are here treated as one. The cleaning, finishing, and shipping department, therefore, may be defined as that part of a gray iron foundry in which the castings are cleaned, chipped, ground and shipped.

Fixed Plant Charges

In a foundry, as in all businesses, there are certain plant charges or expenses of a more or less fixed nature which are not applicable to any one department but which are common to all departments. Expenses under this head consist of power, heat and light, depreciation, taxes, insurance and superintendence. Expenses of this character, where it is practicable, should be distributed over the several operating departments according to the extent each department incurred or shared in such expense. In the larger foundries it is practicable to distribute these so-called fixed plant charges departmentally, but in the smaller foundries it is not generally practicable. Inasmuch, therefore, as this treatise is intended more particularly to fit the requirements of the smaller and medium size foundry, I have shown these general plant expenses undistributed departmentally.

Administrative and Selling

The last general cost division is administrative and selling expense, which comprises all expense of the general office covering both administrative and selling functions.

Definition of Cost Accounts

The second step in a cost structure is a definition of cost accounts. That is, naming or defining what is to be included under each account.

Table 2

STATEMENT OF METAL COSTS

Month of..................192....

Per Cent of Gross Charge		Weight (pounds)	Average Book Price (N. T.)	Book Value
51.3	Pig Iron	400,000	$20.72	$4,144.00
28.2	Purchased Cast Iron Scrap	220,000	18.00	1,980.00
19.2	Home Sprue and Scrap	150,000	18.00	1,350.00
1.3	Steel Scrap	10,000	19.00	95.00
100.0	Gross Charge	780,000	19.41	7,569.00
5.0	Less Oxidation and Metal Loss	39,000		
95.0	Metal Poured	741,000	20.43	7,569.00
18.1	Less Sprue and Scrap Produced	141,000	18.00	1,314.00
76.9	Good Castings Produced	600,000	20.85	6,255.00
	Net Tons	300.0		

Statement of Metal Costs

The third step in a cost structure is the preparation at the end of the month of a *monthly cost statement.* The cost of the metal entering into the month's product can be made an integral part of the monthly cost statement or a separate statement of metal costs can be prepared. Personally, I prefer the latter, and in Table 2 a set-up of metal costs is shown as I would have it prepared.

In this way there is clearly shown, in percentage, pounds

and value, the metal charged into the cupolas during the month, the oxidation and metal loss, the weight and value of the metal poured, the weight and value of the sprue and scrap produced and the net cost of the metal per ton of good castings produced. The total weight of the charge for the month, namely, 780,000 pounds, is obtained from the daily cupola reports. The sprue and scrap produced, namely, 141,000 pounds, is obtained by adjusting the home sprue and scrap melted by the difference in inventories at the beginning and end of the month. In other words, the inventory at the end of the month was 9,000 pounds smaller than it was at the beginning of the month. This decrease in inventory, deducted from the home sprue and scrap melted, 150,000 pounds, gives the sprue and scrap produced. With the known production of good castings and that of sprue and scrap, the weight of metal poured is readily obtained. The difference between the weight of the metal poured and the gross charge is the oxidation and metal loss.

Monthly Cost Statement

The monthly cost statement (Table 3) is a picture of the cost of operations for the month, obtained by setting up in statement form the balances of the cost accounts.

It is a good plan to have the monthly cost statement show both the actual costs for the month and the normal costs, or what the costs would have been had the production been normal in volume.

Normal costs are obtained by adjusting the *fixed plant charges* and *administrative and selling expense* to the basis of normal operations, a production of 60 per cent of normal being assumed for illustration. Normal operations, or a normal production, may be taken as the average monthly output during a three-year period consisting of a good year, a fair year and a bad year, or as some prefer, by taking 80 per cent of the average monthly production for the best six consecutive months.

Direct Costs

Of the items of the *monthly cost statement,* the direct

Table 3

MONTHLY COST STATEMENT

Good Castings Produced......300.0 Tons. Month of................192....

	Actual Cost		Normal Cost*	
	Amount	Per Ton	Amount	Per Ton
Net Metal Cost............................	$6,255.00	$20.85	$6,255.00	$20.85
METAL DEPARTMENT:				
Indirect Labor	720.00	2.40	720.00	2.40
Fuel..	780.00	2.60	780.00	2.60
Supplies and Tools.........................	150.00	.50	150.00	.50
Repair Labor and Materials...............	45.00	.15	45.00	.15
Cupola Relining Expense..................	75.00	.25	75.00	.25
Total......................................	$1,770.00	$5.90	$1,770.00	$5.90
MOLDING DEPARTMENT:				
Direct Labor—Molders' Payroll...........	$5,400.00	$18.00	$5,400.00	$18.00
Indirect Labor.............................	2,310.00	7.70	2,310.00	7.70
Supplies and Tools.........................	780.00	2.60	780.00	2.60
Repair Labor and Materials...............	90.00	.30	90.00	.30
Total......................................	$8,580.00	$28.60	$8,580.00	$28.60
COREMAKING DEPARTMENT:				
Direct Labor—Coremakers' Payroll.......	$2,100.00	$7.00	$2,100.00	$7.00
Indirect Labor.............................	1,530.00	5.10	1,530.00	5.10
Fuel..	300.00	1.00	300.00	1.00
Supplies and Tools.........................	570.00	1.90	570.00	1.90
Repair Labor and Materials...............	45.00	.15	45.00	.15
Total......................................	$4,545.00	$15.15	$4,545.00	$15.15
CLEANING, FINISHING AND SHIPPING DEPARTMENT:				
Indirect Labor.............................	$960.00	$3.20	$960.00	$3.20
Supplies and Tools.........................	300.00	1.00	300.00	1.00
Repair Labor and Materials...............	120.00	.40	120.00	.40
Total......................................	$1,380.00	$4.60	$1,380.00	$4.60
FIXED PLANT CHARGES:				
Power, Heat and Light.....................	$300.00	$1.00	$180.00	$0.60
Fire Insurance.............................	90.00	.30	54.00	.18
Liability Insurance........................	120.00	.40	72.00	.24
Taxes..	150.00	.50	90.00	.30
Depreciation................................	300.00	1.00	180.00	.60
Supt., Gen'l Foreman & Misc. Yard Labor	540.00	1.80	324.00	1.08
Misc. Plant Expense.......................	180.00	.60	108.00	.36
Total......................................	$1,680.00	$5.60	$1,008.00	$3.36
Drayage.....................................	$150.00	$0.50	$150.00	$0.50
Returned Castings and Allowances.........	120.00	.40	120.00	.40
ADMINISTRATIVE AND SELLING EXPENSE:				
Office Salaries.............................	$1,500.00	$5.00	$900.00	$3.00
Office Expense.............................	660.00	2.20	396.00	1.32
General Expense...........................	150.00	.50	90.00	.30
Total......................................	$2,310.00	$7.70	$1,386.00	$4.62
Total Cost of Good Castings Produced......	$26,790.00	$89.30	$25,194.00	$83.98

Normal Production per month..500 Tons
Production during month..300 Tons
Percentage of Normal..60

*Actual Cost, adjusting Fixed Plant Charges, and Administrative and Selling Expense to basis of Normal Operations

costs, or those which can be charged directly to a particular casting or class of work, are:

Net Metal Cost
Melting Cost
Molding Direct Labor
Coremaking Direct Labor
Returned Castings and Allowances

Indirect Costs

All other items on the *monthly cost statement* are indirect costs, or those which cannot be charged directly to the work produced and have to be distributed as an overhead on the basis which will apportion the expense as nearly as possible according to the amount of such expense consumed in making the particular casting or class of work.

Distribution of Indirect Costs

The procedure to distribute indirect costs which has proved by experience to be generally applicable is to:

1. Distribute the indirect costs of the molding department on the basis of the molding direct labor.
2. Distribute the indirect costs of the coremaking department on the basis of the coremaking direct labor.
3. Distribute the costs of cleaning, finishing and shipping department on the basis of the production of good finished castings, applying where practicable the cost of tumbling against the tonnage tumbled and the cost of sand-blasting against the tonnage sand-blasted.
4. Distribute the fixed plant charges, applying 50 per cent on the basis of molding direct labor, 10 per cent on the basis of coremaking direct labor and 40 per cent on the basis of the production of good finished castings. This percentage distribution is not entirely arbitrary but is approximately the proportions of the fixed plant charges in the average gray iron foundry of the smaller size which would be allocated to the molding department, the core department and to the cleaning, finishing and shipping department, respectively, were the charges distributed departmentally.

5. Distribute the cost of drayage on the basis of the production of good finished castings.

6. Distribute administrative and selling expense on the basis of the molding direct labor, or on the basis of units of molding floor space.

Returned Castings and Allowances

The loss on castings returned by customers is recorded on the monthly cost statement but this cost is not included in the overhead as the returns from some customers are heavy and from others light. The defective returns at the end of the month should be analyzed and the invoice price of the castings returned, less scrap value, should be applied directly to the cost of producing the particular patterns of castings returned.

Metal, Melting and Overhead Rates

The metal, melting and overhead rates, using the illustrative normal cost figures of the monthly cost statement, are obtained as shown in Table 4.

Table 4

METAL, MELTING AND OVERHEAD RATES

Net Metal Cost		$ 6,255.00
($20.85 per ton of good castings produced.)		
Melting Costs		1,770.00
($5.90 per ton of good castings produced.)		
Molding Direct Labor		5,400.00
Molding Indirect Costs	$3,180.00	
50% of Fixed Plant Charges	504.00	
Administrative and Selling Expense	1,386.00	
($5,070.00 ÷ $5,400.00 = 94.0% overhead on molding direct labor.)		5,070.00
Coremaking Direct Labor		2,100.00
Coremaking Indirect Costs	$2,445.00	
10% of Fixed Plant Charges	100.80	
($2,545.80 ÷ $2,100.00 = 121.2% overhead on coremaking direct labor.)		2,545.80
Cleaning, Finishing and Shipping Costs	$1,380.00	
40% of Fixed Plant Charges	403.20	
Drayage	150.00	
($1,933.20 ÷ 300 tons of good castings produced gives a tonnage overhead of $6.45.)		1,933.20
Direct Charges:		
Returned Castings and Allowances		120.00
Total Cost		$25,194.00

Product Costs

Costs, throughout the foundry industry, divide themselves into four classes, namely, tonnage costs, class costs, customer's costs (the cost to produce the entire work of a given customer), and job costs.

Tonnage Costs

Tonnage costs are average per ton to produce the entire output of the plant for a stated period. They are arrived at by dividing the amount of the several cost items by the output in tons. In a jobbing foundry, tonnage costs are practically worthless for price-making purposes.

Class Costs

Class costs are a refinement of tonnage costs. That is to say, in addition to determining the average cost for the entire production of the foundry the cost of the product divided into classes is determined. If the product of the foundry is subject to classification the procedure of recording class costs produces dependable results. When class costs are kept, the classification should be one of weight, separating the work as to plain and cored product.

Customer's Costs

Where all of the work of a customer, consisting of a variety of similar or dissimilar patterns has been taken at a flat price, which is often the case, it is usually best to treat the customer's entire product as the cost unit. If different parts of the work take different prices, the work taken at different prices should be the cost unit or cost division. Even though the entire work of a customer is the cost unit, the cost records should be so designed to make it possible to readily determine at any time the cost of any particular pattern of casting.

Job Costs

In the foundry industry, owing to the multitude of patterns produced by most concerns, a somewhat greater amount of clerical labor is required to ascertain job costs than is required to ascertain either class costs or customer's costs. The fact, however,

that the cost of no two patterns is the same is sufficient reason for ascertaining job costs and for demanding a price on each pattern based upon its production cost.

Procedure to Obtain Product Costs

To determine product costs, whether they are class costs, customer's costs or job costs, the procedure is the same. In brief, it is to record by jobs or patterns of castings the costs of the direct labor operations, mainly, molding and coremaking, and to add thereto the cost of the molten metal and the indirect costs or overhead.

Molders' Daily Production Record

The gathering of the molding direct labor by patterns is the first consideration, and the form shown, Table 5, is very suitable for that purpose in the average foundry.

There are two methods of recording the daily production of molders. One is for the timekeeper or cost clerk to record, just previous to the pouring of a heat the name of the molder, the pattern number on which the molder is working, the number of molds poured, the pieces per mold and the hours spent in molding. The other method is to have the molder record the above information. It is preferable to have the foreman, timekeeper or cost clerk gather the information, as then it is more accurate and the workman is relieved of performing any clerical labor.

Molder's Weekly Production Record

The data from the *molder's daily production record* is carried to a *molder's weekly production record,* Table 6, for summarization which record serves both as a payroll record and as a cost record. The clerical labor thus saved is very considerable compared with separate payroll and cost records.

Coremaker's Weekly Production Record

The *coremaker's weekly production record,* Table 7, can be similar to the *molder's weekly production record,* and it likewise should serve both as a payroll record and a cost record.

Table 5

MOLDERS' DAILY PRODUCTION RECORD

Sheet No............. Day. Mon....... Date... Oct. 4,.....1926.

MOLDER	CUSTOMER	PATTERN NO.	MOLDS POURED	PCS. IN MOLD	PIECES				POUNDS GOOD	MOLDING HOURS
					MADE	GOOD	ALLOW	BAD		
Doe	Roe Co.	R 2346	40	2	80	72	—	8	720	7
	A.B. & Co.	72	2	1	2	2	—	—	44	1

Table 6

MOLDER'S WEEKLY PRODUCTION RECORD

Amount 41.40

Molder Doe........ No. 20....... Week ending Oct. 9, 1926

CUSTOMER			Roe Co						A.B. & Co						Foster Machine Co					
PATTERN NO.			R2346						72						230-S					
PCS. ORDERED			1000						2						5					
PCS. IN MOLD			2						1						1					
DATE	TOTAL HOURS		MOLDS POURED	PIECES			POUNDS GOOD	MOLDING HOURS	MOLDS POURED	PIECES			POUNDS GOOD	MOLDING HOURS	MOLDS POURED	PIECES			POUNDS GOOD	MOLDING HOURS
	P.W.	D.W.		GOOD	ALLOW	BAD				GOOD	ALLOW	BAD				GOOD	ALLOW	BAD		
Oct. 4		8	40	72	–	8	720	7	2	2	–	–	44	1						
5		8	50	92	–	8	920	8												
6		6	36	65	–	7	650	6												
7		8	52	98	–	6	980	8												
8		8	20	38	–	2	380	3							5	5	–	–	650	5
9		8	52	100	–	4	1000	8												
TOTAL		46	250	465		35	4650	40						1						5
RATE								90						90						90
AMOUNT								36.00						.90						4.50

Table 7

COREMAKER'S WEEKLY PRODUCTION RECORD

Amount 35.20

Coremaker J. Smith.......... No. 34....... Week ending Oct. 9,.......1926

CUSTOMER			Roe & Co		B.M.Co.		Ajax	
PATTERN NO.			R2346		X40		960	
CORE LETTER								
CORES ORDERED			1100-210		660		8	
DATE	TOTAL DAY HOURS		CORES MADE	HOURS	CORES MADE	HOURS	CORES MADE	HOURS
	P.W.	D.W.						
Oct. 4		8	100	4	140	4		
5		8	110	4½	120	3½		
6		8	126	4½	100	3½		
7		8	80	3	162	5		
8		8	116	4	128	4		
9		4					8	4
TOTAL		44	532	20	660	20	8	4
RATE				80		80		80
AMOUNT				16.00		16.00		3.20

Table 8

SUMMARY COST RECORD

Customer Roe & Co.
Pattern No. R2346

Pounds Per Casting 10.0
Pieces Per Mold 2

☑ Bench ☐ Squeezer ☐ Plate ☐ Floor ☐ Machine

Week Ending	Molder	Molds Poured	Pieces Good	Pieces Bad	Pounds Good Production	Molding Hours	Molding Labor	Core Hours	Coremaking Labor	Patterns and Flasks			
Oct 2								[illegible]	4 40	3 80			
9	Dm	250	465	35	4650	40	36 00	20	16 00				
16		290	540	40	5400	46	41 40	16	12 80				
		540	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3 80			

Table 9

COST CARD

Customer Roe & Co
Pattern No. R 2346

Pounds Per Casting 100
Pieces Per Mold 2

	Oct '26						
Pounds Good Production	10,050						
Production per Molder per Hour (Lbs.)	117						
COSTS PER NET TON:							
Metal	20 85						
Melting	5 90						
Molding Direct Labor	15 40						
Molding Overhead	14 48						
Coremaking Direct Labor	7 00						
Core Overhead	8 48						
Tonnage Overhead	6 45						
Direct Charges (Patterns, etc.)	3 80						
Total Cost Per Ton	82 36						
Cost Per Cwt.	4 12						

(Belt Foundry Cost Form 64)

Table 10

COST ESTIMATE

Name Roe & Co.
Pattern No. R2346

Date of Estimate Sept. 29, 1926
Class of Work Auto

Pieces	Lbs. Per Casting	Pcs. Per Mold	Lbs. Per Mold
1000	10.0	2	20.0
Molds	**% Loss**	**Molds to Make**	**Cores Required**
500	8	544	1100

Total Good Production 10,000 Lbs.
5 Tons
Molds per Molder per hr. 6
Good Production per hr. 120 Lbs.
per day 960 Lbs.
Cores per hour 22

DAY WORK

Molding Hours 91 Rate 90 Total 81.90
Coremaking Hours 50 Rate 80 Total 4000

PIECE WORK

Molding Cost per 100 molds .... Total ....
Core Cost per 100 molds .... Total ....

(Belt Foundry Cost Form 60)

	Total Cost		Cost Per Ton	
Metal Cost ($ ...... N.T.)			20	85
Melting Expense ($ ...... N.T.)			5	90
Molding Direct Labor			16	38
Molding Overhead (94 %)			15	40
Coremaking Direct Labor			8	00
Core Overhead (122 %)			9	76
Tonnage Overhead ($ ...... N.T.)			6	45
Direct Charges:				
Total Cost Per Ton			82	74
20 % Profit ($ 7.94 per Floor per Day)			16	54
Selling Price Per Ton			99	28
Per 100 lbs.			4	96

Summary Cost Record

The *summary cost record,* Table 8, is suitable with minor changes to record either customer's costs, class costs or job costs. The form shown is that for recording job costs. The name of the customer, pattern number, molds poured, pieces made, pounds good, molding hours, and the molding direct labor are obtained from the *molder's weekly production record,* Table 6. The coremaking direct labor is obtained from the *coremaker's weekly production record,* Table 7. At the end of the month or accounting period the sheet is totaled and the results carried to the Cost Card which expresses the costs in units of production, per ton or per hundred pounds.

Cost Card

The production cost of each important pattern of casting, of each different class of work produced, or of the entire work of a customer by months or by quarters can now be conveniently summarized on a card form for the use and guidance of the sales executive. A *cost card* in the form shown, Table 9, will be found to be invaluable for price-making purposes.

The metal cost ($20.85 per ton of castings produced), and the melting cost ($5.90 per ton of castings produced) are obtained directly from the monthly cost statement.

The molding direct labor ($15.40 per ton), and the coremaking direct labor ($7.00 per ton) are obtained by dividing the respective costs as shown on the *summary cost record* by the weight of good production.

The overhead on molding direct labor ($14.48 per ton) is obtained by multiplying the molding direct labor ($15.40 per ton) by the overhead rate (94.0 per cent).

The overhead on coremaking direct labor ($8.48 per ton) is obtained by multiplying the coremaking direct labor ($7.00 per ton) by the overhead rate (121.2 per cent).

The tonnage overhead ($6.45 per ton) is the same on all work.

The total cost per ton is found by addition and is expressed also in dollars per hundred pounds for ready reference in hundred-weight or pound units. A line is provided on the form for the insertion, if desired, of the price per hundred pounds.

This completes the cost-finding procedure, which, I think you will agree, is not complicated and yet a cost on any important pattern of casting or on every pattern of casting can be had with a surprisingly small amount of clerical labor.

Estimate Sheet

One of the principal uses which can be made of dependable cost information is in estimating on new work, and an estimate sheet is in a way needed for the full presentation of my subject. Before quoting on new work, an estimate should be orderly and carefully prepared and systematically preserved so that the estimate, item by item, can be checked against the cost record after a cost on the work has been established. A comparison in detail is of special benefit in disclosing items either entirely overlooked or regularly underestimated, both of which are very common.

The form of estimate sheet, Table 10, is suitable for foundries whether their work is so-called production or jobbing. The unit costs and overhead rates shown on the estimate sheet are those used in Table 4 as in that way the relation of the monthly cost statement to the estimate sheet can be clearly seen.

Explanation of Estimate Sheet

An inquiry, we will assume, calls for 1000 pieces, weighing 10 pounds each, with two pieces per mold, or 20 pounds of castings per mold. To produce the desired quantity, therefore, will require 500 good molds. If it is estimated that the foundry loss will be 8 per cent, it will be necessary to put up 544 molds to get 500 good molds or 1000 good pieces. And if a molder is able to put up 6 molds per hour, it will require 91 molding hours to produce the job. At a molding rate of $0.90 per hour, the molding direct labor would amount to $81.90, or $16.38 per ton.

The casting takes one core, and to produce 544 molds requires 1088 cores. Allowing for a small breakage, 1100 cores would have to be produced. If a coremaker is able to produce 22 cores per hour, it will require 50 coremaking hours to produce the required number of cores. At a coremaking rate of $0.80 per hour, the coremakiing direct labor would amount to $40.00, or $8.00 per ton.

The metal cost of $20.85 per ton and the melting expense of $5.90 per ton are obtained directly from the monthly cost statement.

The molding overhead, or the costs which are variable with molding direct labor, is found by applying the overhead percentage (94.0) to the molding direct labor.

The coremaking overhead is found by applying the overhead percentage (122.0) to the coremaking direct labor.

The tonnage overhead, or the uniform costs which are the same per ton on all classes of castings, is $6.45 per ton.

Under the head of "direct charges" would be included any special expense of producing the work, such as flasks, patterns, drilling, etc.

The total estimated cost of the job, namely, $82.74 per ton, is found by addition.

To the total estimated cost per ton is added a profit of 20 per cent which amounts to $16.54 per ton, and which is equivalent to a profit of $7.94 per floor per eight hour day. In other words, the profit on the day's production of 960 pounds would be $7.94.

An estimate correctly and accurately prepared along the above lines, utilizing the information shown by the cost records and taking into consideration every element of cost, is the only reliable basis upon which a price on new work can be safely and intelligently made.

Discussion

Mr. Harper: I would like to ask Mr. Belt how he disposes of his foundry tools, those that are cast. Do you consider them good castings and do they enter into the cost in that way, and all the molding labor that is put on these tools, how do you dispose of that in your setup as you have it here?

R. E. Belt: Well, in most of the foundries the production of the so-called shop castings are relatively small. In the large foundries the work for their own show is a very considerable item and where that is the case it is necessary to include in your production for the month your commercial tonnage as well as the tonnage for your own use. And I recommend that separate costs be kept on shop equipment just the same as you would keep on your commercial production.

Mr. Harper: Then you consider them good castings and charge them out as such?

R. E. Belt: Yes, I would recommend treating the cost of your shop equipment the same way as the commercial work, if you go through the entire manufacturing process. In some branches of the foundry industry there are shop castings in the malleable iron branch that don't go through the entire manufacturing process, and, of course, there the cost should stop when the production stops on work of that character.

Mr. Harper: In the breaking of some of the castings would you put them in as scrap?

R. E. Belt: I would put them in as scrap value.

Mr. Harper: And the difference would be carried in the over-head?

R. E. Belt: That is a cost that must be absorbed under some head, of course. It is really a separate depreciation on equipment, or it is the cost of equipment that is used in service.

Mr. Hansen: In the estimating of profits, you advise both the percentage and the floor figure. You recommend the percentage basis and the floor figure, too.

R. E. Belt: I really think the profit per day per floor where your units of molding floor space are well defined is a better criterion of the profitable measure of the work than a percentage. You will find some jobs where 20 per cent, we will say, on a casting will not pay, due to some peculiarity of the job, an adequate return, and in those cases your return per floor will reflect that situation. That is the reason for showing that and comparing the profit determined by percentage and the profit per floor per day. Of course, there are a number of foundries where the units of molding floor space are not well defined; that is particularly true of the floor work. On the other hand, on bench work your units of floor space are pretty well defined.

Chairman A. E. Hageboeck: I take it Mr. Belt, that it is your idea that you want to make as much profit on a job, for instance, where he would only get 300 pounds per day as you do off of the floor right next to it where a man is getting 800 or 1,000 pounds per day.

R. E. Belt: Yes. Otherwise, you are not getting a fair return on your investment.

Chairman A. E. Hageboeck: I have been in foundries where they just add so much per pound and it is dead wrong.

Handling Materials in a Foundry

By E. T. Bennington,* Wickliffe, O.

It is remarkable to note the many different material handling methods employed to accomplish the same results in the various industries. For instance, a roll of cloth in the textile mill will be handled in and out of storage in an entirely different method from that employed to handle rolls of paper of about the same size in a paper mill. Our company recently installed a sheet stacking device in a large steel mill which employed a principle of operation that has been used for stacking sheets of paper in printing establishments for a great many years. For some reason or other the steel mill engineers did not see the possibility of adopting a similar device for their own business and we venture to say that there are not many steel mill engineers who today know of the commonly used stacking device in print shops, although the engineer of one steel mill has a very intimate knowledge of the kind and number of tinning machines or any other type of production machines used by his principal competitors. It is our observation that men of one industry exchange ideas with men in the same industry but we question if they exchange ideas enough with men in entirely different industries, or in industries that manufacture an entirely different product.

The writer is not a foundryman and is not going to tell you how to make castings. He is in the material handling business and follows its development closely, and believes he can tell you enough about what all industries are doing with material handling machinery to at least give you some ideas to think about.

Two Principles in Material Handling

In spite of the fact that the various industries use different methods to accomplish the same results of material handling, there are two fundamental principles that are employed in every successful material handling installation regardless of the industry in which it is used. Principle No. 1 is to "increase the size of the unit of production" and principle No. 2 is to "pick up the load where it is and take it to its destination without rehandling."

*Manager Cleveland Electric Tramrail Division of the Cleveland Crane and Engineering Co.

Engineers throughout the country are fast beginning to realize the tremendous importance of principle No. 1, to increase the size of the unit of production. Not over five years ago the largest bundle of wire produced by any wire mill weighed one hundred and fifty pounds. When the Minnesota Steel company at Duluth built the new wire mill they installed wire drawing equipment and installed material handling machinery to handle bundles of wire weighing three hundred pounds. More than one wire mill engineer told us that the new mill would be a failure, but today there is not a large wire mill in the country that rolls a bundle smaller than three hundred pounds and many of the small mills have revamped their machinery to increase the size of the bundle. In many cases they had to do it or go out of business. We just recently learned that there is a new wire mill under process of construction that will roll and draw a seven hundred and fifty pound bundle. The reason savings are effected by increasing the size of the unit of production in a wire mill is due to the fact that a block drawing a three hundred pound bundle of wire need be stripped only half as often as if drawing a one hundred and fifty pound bundle, with the result that one man can take care of twice as many blocks and can keep all of the blocks more continuously producing wire and not shut down so often to be reset with new bundles. The same principle holds true in a galvanizing process department, as well as in processes making nail rivets, barbwire, etc. With the larger bundles these machines don't have to be set up and started so often. The saving in labor is tremendous. Of course the use of large bundles makes it necessary to use material handling machinery and as long as material handling machinery must be used there is no reason why the unit of production in a wire mill should stop at three hundred pounds. A seven hundred and fifty or thousand pound bundle is thoroughly practical and it won't be many years before it is the common unit of production.

Size of Units Handled Increased

It was not many years ago that the common warp beam used in the textile mill weighed fifty pounds and men carried the beam about the factory on their shoulders. We have seen

the size of the beam rise to one hundred and fifty pound, then three hundred pound and there are a few mills about the country that employ a six hundred pound beam. In some of these textile mills the six hundred pound beam will keep a machine running two weeks continuously before the machine is shut down to receive a new beam. It usually takes several hours to start a new beam in the machine, but it does not take any more time to start a six hundred pound beam than it does a fifty pound beam but the nonproductive time on the machine is only one-twelfth of what it would be if a fifty pound beam was used.

Our company recently installed material handling machinery in the largest artificial silk plant in the world to handle artificial silk on a one ton spool. The rubber mills in the past few years increased the size of rolls of friction fabric from three and four hundred pounds to a ton and over, with a tremendous saving of nonproductive time on the calendars, bias cutters, etc. Paper mills all over the country are increasing the size of the rolls of paper which they produce. Bakeries are baking bread in one ton lots where they used to handle and bake bread in a manner which practically amounted to baking them in individual loaves.

Some bolt and nut factories are handling the products about their plant in one ton units, where they formerly handled them about the plant in fifty pound tote boxes. Candy factories are cooking, pouring and mixing their candies in ladles that weigh from five hundred pounds to a ton. Ice plants are pulling entire rows of cans from the freezing mixer where not many years ago they were drawing single cans at a time and in some cases did not employ machinery for this purpose.

Foundry Units Increased

And last, but by no means of least importance, the foundries are increasing the size of the ladles and flasks. Some foundries are pouring molds from ladles weighing fifteen hundred pounds. We are going to show you a slide of one foundry that installed flasks eight or ten feet long and a molding machine to set up molds in these flasks with material handling machinery to handle the flasks and handle the ladle while pouring, and also to handle the castings to the cleaning room. In this case the product was

cast iron pipe but if the product had been valve castings or pipe fittings or any one of a thousand different castings that are made today, we know there are many foundrymen who would say that it would be impossible to cast fifty or a hundred small castings in a flask of the proper size and probably would prove that they were correct in their contention.

We know many wire mill engineers will tell you that no wire mill will produce a seven hundred and fifty or thousand pound bundle of wire successfully, and if you want to go into details with them about the matter they will prove that it cannot be done. But in a very short time you are going to see it done successfully and you will find the engineers who say today that it cannot be done doing it in their own plant. When the plans for the new wire mill at Duluth were first announced we recall that one of our good friends, who was superintendent of a large wire mill, was positive that the new mill would be a failure. We went into the subject with him in considerable detail, as we were involved to some extent in the plant at Duluth, and he almost convinced us that it could not be made to work, but less than three years later we helped him design and install machinery to take care of three hundred pound bundles in his own plant. There is no doubt but what the foundries are going to have to fall in line with the other industries. Larger units of production in foundries are surely coming. Larger ladles and larger flasks with more castings to a flask or to a pattern and with these larger units of production we will see material handling machinery used more extensively. In the majority of foundries today the size of the flask is limited to the weight that one or two men can lift, but when the lifting is more generally done with machinery the size of the units of production will increase rapidly.

It is not only the size of the ladles and flasks that can be increased and the size of the bucket or unit that conveys the rough castings into the cleaning room, but the size of the tumbling barrel and rattler will also increase the material handling efficiency. A tumbling barrel that will clean one or two ton of castings will clean its charge just as quickly as a smaller machine that cleans only four or five hundred pounds. If the nature of

the castings to be cleaned will permit the use of larger units, and practically all castings are so adapted that they can be cleaned in a larger tumbler, the cost of doing the cleaning will be materially reduced.

Application of Principle No. 2

Principle No. 2, is to pick up a load where it is and carry it to its destination without rehandling it. This is the principle of material handling that is just as important as Principle No. 1, and we believe that Principle No. 2 is capable of much wider application to foundries. There are a great many material handling machinery applications in foundries that are laid out without due regard to completing the handling of a load in one operation.

We recently visited a foundry that had just completed an installation of an elaborate system of material handling in which was employed many kinds of material handling machines. Roller conveyors, slat conveyors, monorail systems, cranes and belt conveyors were used extensively. To describe one cycle of operation in connection with the handling of flasks and molds, a monorail system was employed to remove a mold from a large molding machine and place it on a slat conveyor on which it was moved to a point where the pouring was accomplished from another monorail system. As this mold continued to travel along the conveyor the casting was given sufficient time to set, the flask was picked up by another monorail system, shaken out and then conveyed to an inclined roller conveyor where the empty flask was returned in the general direction of the molding machine. At the end of this roller conveyor it was again picked up by a monorail system and conveyed to the molding machine.

In many other industries we have seen a load just as fragile in nature as an unpoured mold handled through many operations by one type of material handling machinery. We believe that manufacturers of slat conveyors would install their machines in such a way that they would handle this flask through the entire operation of pouring, shaking out and returning the empty flask without necessitating the rehandling of the flask and we know positively that monorail builders would have picked the flask off

the molding machine in such a way as to permit the cores to be set before closing the molds and carry the flask through all the operations of pouring and shaking out and returning the empty flask to the molding machine without rehandling and at a considerable saving in labor.

T. C. Flinn told the foundrymen at the convention in Syracuse that he had discovered, after making a very thorough study of the subject, that the brass foundries would probably average one hundred and fifty-two tons of material handled in order to produce one ton of castings and that the iron foundries would probably average two hundred and six tons of material handled in order to produce one ton of castings. This means that the same material is handled over and over again. We know that a great many rehandled operations can be eliminated in foundries and without increasing materially the cost of the material handling machinery. We know of no other industry that handles so much material, or rather rehandles so much material, to produce one ton of product.

Core Room Applications

Principle No. 2 can be applied to the core room. The application of material handling machinery would have to be approached in an entirely different manner. Many other industries have successfully applied material handling machinery to problems that are exactly the same from a material handling standpoint.

We will later show you slides of a pottery in which ceramic tanks are handled through the operations of molding, dusting, drying and to the kilns without rehandling. It is not a difficult problem to handle cores from the core bench into the oven and out of the oven to storage or to the molding floors in one ton lots and without rehandling the cores separately. We would usually recommend that when in storage that they be not rehandled but left on the rack in which they were originally placed. A rack on wheels or on a skid does not cost much more than a good rack on the floor and if it is on wheels or on a skid it is capable of being moved as a unit and it saves handling. To our mind the greatest opportunity for the practical applications of principle No. 2 in the foundry is on the molding and pouring

floor. There are porbably more tons of material handled in molding, pouring and shaking out than at any other place in the process of making castings. There is a possibility of applying material handling to these operations in such a way as to make the department almost automatic. We have seen equipment at different foundries about the country which if brought together in one plant would make what is practically an automatic foundry. In one foundry in southern Illinois we have seen an automatic molding machine that received an empty flask at one end, the flask traveling through this machine, the drag first and the cope following, the sand as first applied and rammed, then the pattern was drawn automatically after which the cores were set by hand and the flask closed. This molding machine produced eighty complete molds per hour, the molds being about three by four feet containing four different castings.

There is another foundry in Pittsburgh that has a very efficient means of shaking out a flask and returning the empty flask to the molding machine without rehandling. There is a plant in New York State that has installed an automatic system of conveying castings from the shake-out to an incline rattler that receives the castings at one end and the castings rattle through the machine about thirty feet long where they are discharged at the other end without the aid of a man at any point. There are a number of foundries throughout the country so equipped that the flask is removed from the molding machine and conveyed to a point adjacent to the cupola or furnace where it is poured.

Bringing Automatic Handling Equipment Together

With the proper use of material handling machinery we believe it is possible to bring all of these automatic operations together in one plant. If this principle can be applied to one foundry it will mean that in addition to the men required at the molding machine only a very few men will be needed to deliver clean castings to the finishing floor or shipping department. One or more men will be required at the cupola or furnace to take care of the pouring and one man at the shake-out to lend a hand if castings stick or if flasks do not separate as they should. We are sure that the material handling machinery manufacturers will take care of the material handling part of such a foundry.

The foundrymen will have to supply the molding machines or several molding machines that will deliver finished molds preferably at a high rate of production.

To complete this picture the foundrymen should supply a spout or reservoir at the cupola or furnace that will permit molten metal to run directly from the furnace into the flask, that is brought to the furnace or cupola on the conveyor. This device should be so constructed that the metal will pour from the bottom something on the order of a steel mill foundry ladle and have a reservoir above to permit slag to collect where it can be skimmed off. With such a device a mold can be propelled under the spout and brought to rest until poured and then started in motion again. Such an application for the molding and pouring floor would be applying principle No. 2 in a very efficient manner.

Most foundries want to get the metal into the molds as hot as possible, particularly the malleable and brass foundries. We don't know of any way in which this can be accomplished with greater efficiency and with greater assurance that the metal will reach the mold hot than by pouring the molds right from the furnace. We know very well that some foundrymen will say that automatic or semi-automatic molding, pouring, shaking out and cleaning is impossible to accomplish in a practical way in spite of the figures of material handled to produce one ton of castings, just as our wire mill friend said that three hundred pound bundles in a wire mill was impossible to accomplish.

We have been in foundries that have spent thousands of dollars for material handling machinery that pride themselves on the fact that they have applied material handling machinery to every operation, but the material handling machinery consists of a hoist here, a monorail system there and a roller conveyor or slat conveyor at various points about the plant. They applied material handling machinery to the handling operations but they did not eliminate the handling operation or they did not apply principle No. 2 as effectively as they might have done, with the result that the material handled to produce castings was still very high and the payroll per ton of castings was not materially reduced, although the physical labor involved in producing the castings was probably materially reduced.

Discussion

H L. McKinnon: One thing that occurs to me with regard to any suspended type of conveyor, and that is that in all the estimates which I have made over a period of 15 years studying this question, the overhead system invariably costs more than that placed on the floor, for similar loads and similar equipment. That is one thing.

A second thing is that the overhead system interferes with light in the foundry to a greater extent than any floor system, and for that reason I have come to the conclusion that while the monorail system has its advantages and uses in certain places, yet I think for the handling of molds in a foundry it is really working against itself. Some of the earlier installations in this country were on a continuous principle; for instance, a lot of the equipment that Ford put in the River Rouge Plant was of the suspension type, but the oldest installation that I know of in the country is a floor type conveyor that was in successful operation to my certain knowledge for 32 years, and that is a pretty good evidence of the length of life of such equipment and that it can stand up under very severe service.

With regard to the last slides that Mr. Bennington showed, I happened to meet the inventor of that scheme in Detroit last summer; in fact, he is a resident of this city, and he believes very firmly in his idea that sometime he will find an honest city government which will see the advantages of overhead suspension. But, personally, I think the problem of suspending anything in the air and providing an overhead foundation instead of one underneath will undoubtedly prove the stumbling block. There is no question but that the track can be maintained in better condition overhead than underneath, because there isn't the same chance to collect dirt and other things, but, after all is said and done, in every estimate that we have made—and we have made hundreds of them—in comparison between the so-called elevated systems, and the ground systems, the ground systems have shown up to be more economical in the total cost of plant. I believe in carrying a package as far as possible, but I also believe that the only answer to any of these problems is the total man power required from one end to the other.

I could point you out equipment in this city where, with four men altogether, including yard and cupola, they are charging 150 to 160 tons of metal a day, and they are doing that in less than 8 hours. I sold two more equipments like it last week to go to another city. Those things are being done, but they are not being done, as a rule, by monorail systems. The one I refer to includes a gantry crane and a skip hoist and the necessary yard cars and trackage, and four men are handling 150 to 160 tons of metal each day.

E. T. Bennington: I might say this with regard to Mr. McKinnon's remarks. Mr. McKinnon undoubtedly voices the opinion of the majority of foundrymen, that the overhead system is more expensive, but in later

years that is not proving to be the case, and I think that all of you will agree that the use of overhead systems is growing very rapidly. I am not going to say definitely as to foundries, but I will say as to the industries as a whole it is growing very rapidly, it is increasing by leaps and bounds right along. The obstruction to light is probably quite a factor, but as I have seen most foundries, if they just wash their windows a little bit, they will do a lot more in getting some light in there than all the rail in the world will ever hold out.

To defend the overhead system, I think it has some real advantages over anything operated on the floor. It does not obstruct the passage, and I have in mind now an installation that our company is making involving 14,000 feet of rail, doing a job which has always been done on floor trucks before, and there is absolutely no question but that it is going to be a big saver. It is costing them a lot of money, they went into it thoroughly and they know what they are doing.

There is a place for floor conveyors, I don't want to be too strong on that point, there is certainly a place for floor conveyors on all sorts of material handling jobs, but I believe a foundry of all places ought to have their stuff overhead, and I would say that even though it cost two or three times as much as floor operated equipment.

J. R. White: I would like to ask a question of Mr. McKinnon, getting back to cupola charging, because I am particularly interested in that. You made reference to charging this cupola with the skip hoist. Is it possible to get proper charging and an even distribution of the charge and proper layering by using the skip hoist?

H. L. McKinnon: It is on cupolas of any reasonable size, say 80 inches or over, there is no difficulty whatever; or, if the skip hoist equipment is made proportionately smaller, it can be reduced to lower quantities.

Chairman B. D. Fuller: Mr. McKinnon, you say 80 inches or over. You mean lined, or outside shell?

H. L. McKinnon: Eighty inches outside.

J. R. White: As I understand it, that charge would go in from the side, wouldn't it?

H. L. McKinnon: The arrangement is made to deliver at any point, at the will of the operator. The skip is controlled by a drum type controller and the speed at which the skip is allowed to drift in will determine the exact point at which the material will drop and the spread it gets. It has been in successful operation for two years and the people who use it think so well of it that they ordered two more equipments just one week ago.

J. R. White: Well, I can't see how you keep your charge from piling up mostly on one side, that is, the side you put it in. Probably the best

charging practice is hand charging, if you can count on your men, that is, where they could put a shovelful here and a shovelful here and distribute it evenly. I have in mind a system which is increasing right along and being used more and more by foundries, a bottom dump bucket method. The bucket is so arranged that after you have run it into your cupola, a trip line is pulled and it drops that charge down evenly, a perfect layering over the entire surface, which I can't see would be possible with a skip hoist, which would be practically the same thing as putting it all in at one place, one side.

H. L. McKinnon: The point of delivery from the skip hoist itself can be varied for a distance of four feet. It is just a matter of forming the guides properly for the dumping position and the position at which the skip begins to dump and where it finishes dumping, there is quite a space between the two and a perfect layer can be laid right straight across without requiring any skill on the part of the operator. It is merely a matter of teaching the operator to give it a certain length of time in which to do the work. We are handling charges, I may say, of approximately two tons on that equipment, that is the size charge that is going in, two tons of metal, and an equivalent volume of coke, or approximately that, the coke is cut down to make the proper proportions for the melt in the cupola.

E. T. Bennington: In that installation you referred to, how are the skip hoists loaded? What is the handling operation in connection with getting the stuff up to the cupola?

H. L. McKinnon: They use roller bearing cars on tracks in the yard, with one transfer car. There is one man on the crane who fills the cars, on a gantry crane. Then there are two operators handling the cars to and from the skip. The skip is not what you would consider a skip in ordinary terms, but is a platform with a locking device. The car rolls on the platform, is taken up, and the car itself is the bucket that dumps into the cupola. The guides straddle the cupola on both sides, so that the track is carried right past by this specially designed truck that carries this car into position. The car itself is put inside the cupola, but only for the instant in which that work is going on, and any size car can be used that is desired. This is a two-ton car and the total load handled, including the platform, is about 9,000 pounds. A 40 horsepower engine is used to handle the equipment. It doesn't require that, but they wanted excess of power on account of the use of the drum type controllers. It really should be equipped with about a 25 horsepower motor to do the work, if it was being cut down to the most economical basis.

J. R. White: Are all the charges dropped from the level of the door?

H. L. McKinnon: Yes, sir.

J. R. White: Well, with a bottom dump bucket it is possible to lower that bucket as you are building up your charges and you do not have to drop your charge from the level of the door, which I do not believe is good practice. You are able to build it up by means of your hoisting cables, which will lower the bucket on the first charge down toward the bottom, the second charge a little higher, etc. Therefore, your charge doesn't get all of that drop, which I don't believe is good practice.

H. L. McKinnon: Well, that was a criticism that was made of the system at the start, but the owners of the plant stated to me no later than today that there was no damage to the lining greater than occurred with any other method of charging, even the hand charging, and on the hand charging, of course, they drop the stuff from the same level as we are dropping it with the method that is mentioned; but they did take this precaution in regard to about a five foot ring around the top—instead of using ordinary bricks for that distance, they used a cast iron brick lining for the first five feet, just around the top. Now, their chief engineer told me a few days ago that he didn't know that that was necessary, but he thought it was desirable, because unquestionably we do throw some of those charges with a little more force than if you were charging by hand, and possibly more than when you drop from a drop bottom bucket, although a drop bottom bucket will give a very nice distribution, it can't help but give it. Yet, we get, apparently, from this method, just as even layers and just as good distribution as can be obtained in any of the other methods that have been in use.

C. B. Connelley: I would like to ask Mr. Bennington whether or not the electric equipped ladle travels, and, if so, how far.

E. T. Bennington: No, the electric equipped ladle pushes by hand along the rail. However, if it is on a crane, if the nature of the pouring floor is such that you have to cover every square inch of floor space, rather than to cover a line of large flasks in a row, the crane itself can be moved by hand by pushing on the ladle or the carrier.

C. B. Connelley: Then the only electrical control is that of tipping the ladle.

E. T. Bennington: No, it is that of raising and lowering the ladle as you pour. You tip it manually.

Chairman B. D. Fuller: I guess the foundrymen can all appreciate the value of that. It looks good to me.

E. S. Cohen: I would like to ask something about the comparison Mr. Bennington made between the use of a monorail system for material handling in other industries as compared to the use of it in the foundry. In the other industries it is mainly a question of material handling, just the same as in a conveying system for the handling of stone or other build-

ing materials, it is a question of carrying the materials from one point to another. But it seems to me that in the foundry we have a problem of certain production operations intermixed with the material handling proposition, and that is where the overhead monorail system is not as efficient, to my way of thinking, as the floor system, as Mr. McKinnon brought out, because of the fact that you have certain intermediate operations to contend with there, that makes it necessary to set something down and pick it up again, because by doing so you will cut down your total man power. That is why I say if you went to a time study I think you could prove that.

E. T. BENNINGTON: That is the point, but let me say this for the other industries. Every one of them have their problems, Mr. Cohen, and I have seen them from a distance, and, knowing as much about one situation as I do about the other, which may or may not be very much, nevertheless, I have seen the foundries operate and seen the potteries operate, for instance, and I know positively that the handling of ceramic ware in a pottery is just as difficult a proposition as handling a mold. There are just as many intermediate operations, if not more. I mean by that in a foundry that uses the old way of putting the stuff up, by hand, and other types of conveyors. I will agree with you there are occasions when there are intermediate operations, when you have to stop to perform those operations, but I know positively that those operations are not simplified to the limit. Foundries are going to progress in the material handling—the foundry is primarily a material handling proposition—and that is the way you are going to do it.

E. S. COHEN: I am speaking of the molding and core setting and that end of it. I agreed with Mr. White that the monorail system is the most logical system for handling materials from the yard into the cupola. There you can pick up the material and carry it continuously until you are through with it, you have no intermediate operations, and that seems to be the logical method. But in the foundry itself in the core setting and molding operations it is necessary to depend upon various types of molding machines, according to the type of work on hand, but it will be a long time before you will see a monorail system as successful as the floor system for continuous pouring operations.

E. T. BENNINGTON: We cannot agree on that, but we will have to let it go at that, Mr. Cohen.

E. LONGDEN: I would like to ask Mr. McKinnon a question as to whether he has fully detailed the total amount of labor to charge 150 tons of metal.

H. L. MCKINNON: Absolutely. One man on the overhead gantry crane with a weighing device, two men pushing the cars in the yard, one man handling the conveyors for the hoist. The loading is done with

the crane into the cars. There is a little hopper that holds a carload on the gantry crane and the crane man picks the stuff up with a magnet in the yard, puts it in that hopper, and the men who are pushing the cars merely open the gate when they get a charge, then push the car on out of the way. Is that clear?

E. S. COHEN: Mr. McKinnon, may I say something? I think you would probably make it clearer if you would make it plain that the charges in that particular case are very large compared to the ordinary practice.

H. L. MCKINNON: I mentioned it was two tons.

E. S. COHEN: No, I mean the complete charge that they put in; with three layers of coke, it is more than two tons, isn't it, in that particular shop? I understood their complete charge in their particular shop was 10,000 pounds.

H. L. MCKINNON: They are using 200 pounds of coke to the ton net, and I think you are right, that there is from five to six tons in the charge. They weight two tons at a time; the car holds two tons.

E. S. COHEN: But those are different materials.

H. L. MCKINNON: That is the pig iron, that is a single weighing.

E. S. COHEN: Then they weigh their scrap.

H. L. MCKINNON: But that is put in cars of two tons each, also.

E. S. COHEN: But if you were to have the small charge you ordinarily have, you would have that many more weighings to make for, for instance, a 160-ton melt in a day, than you do with this proposition.

H. L. MCKINNON: That is true, but I mentioned the two tons particularly because that is the weighing unit.

W. D. MOORE: I am a long ways from home, but I think I know the installation they are talking about and I happened to be studying those things two years ago and I think it is only fair in mentioning the man power that they do to mention along with it the type of mixture that they are making. If I understand the unit they are talking about, they use practically one kind of material only, and two at the most, where in most of our foundries we have to make a mixture of anywhere from five to ten different types of material, and we are never able to duplicate that with that gantry crane and with that number of men. I think that installation is the most remarkable one I ever saw for man power, but I don't think it is fair to state that without stating the fact that you are using only one or two different kinds of material.

H. L. MCKINNON: We are using three at present.

W. D. MOORE: That is still low.

Saving in Foundry Handling with the Electric Industrial Truck

By H. J. Payne*, New York, N. Y.

Handling materials in the foundry constitutes an element in the cost of producing castings that represents a large fraction of the total production expense. Max Sklovsky, chief engineer of Deere & Co., has ascertained[1] that 96 per cent of the total effort involved in foundry operation goes into the performance of work of this kind. In a special study of the problem he found that to turn out a ton of marketable castings, 26 tons of metal, 12 tons of core material, 74 tons of sand, 51 tons of miscellaneous equipment, almost 1 ton of coke and lime and approximately 2 tons of materials not readily classifiable, have to be moved. This makes a total, when worked out in terms of a unit production, of 100 tons of castings that runs to 16,820 tons. When other handlings that are essential to the conversion of the raw materials into the product that is finally marketed are added to this tonnage, it is found that a total of 224 tons of material have to be handled per ton of product.

One progressive foundry that has kept an exact record of the cost of handling over a period of several years has found that this item runs 19.5 cents per ton per handling. Inasmuch as this particular foundry has employed electric trucks and other types of modern equipment over the period in which records have been kept, it is safe to assume that this figure is lower than the average that would be found to hold in the industry if similar data on a large number of foundries were available.

There can be no question that the use of mechanical equipment for aiding the workers engaged in the transportation of materials in the foundry is worth while. Recognition of this has been general, with the result that very few plants are now attempting to operate without at least a few units of materials handling

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*The Society for Electrical Development, Electric Industrial Truck Department.
[1] The Foundry, April 15, 1921.

equipment. It is certain, however, that the industry in this country is by no means equipped adequately as yet—that much progress remains to be made in the application of existing types of apparatus to local foundry problems. There is the further and most important consideration of adequate synchronization of equipment in such manner as to derive the greatest possible benefit through its employment. The use of cranes, tramrails, hoists, conveyors and power trucks must be co-ordinated not only with process operations but also each handling unit should be made to tie into the handling facilities as a whole.

Certain difficult working conditions have to be met by any type of equipment that is to function successfully in the foundry. Air filled with grit has to be contended with, runways are likely to be in poor condition (despite that good runways yield high profits), periodic overloading of almost any type of equipment has to be considered. Beyond being fool-proof in construction, readily cared for and readily operated, it is absolutely essential that mechanical labor aids shall promise uninterrupted performance. Equipment that is down in an emergency introduces a difficulty that is too expensive to be tolerated if it can possibly be avoided.

No Equipment Universally Useful

Like patent medicine, any type of equipment useful for handling materials has its limitations—especially when weighed against these basic demands which are always supplemented by other conditions peculiar to any given plant. To hold that the electric industrial truck—that type of equipment with which this paper is particularly concerned—is free from such limitations would be to discount its very definite merits. This equipment has, however, made a record that justifies placing it high in the list of labor aids, not only for general handling, but also for such special operations as moving green cores, handling annealing pots, charging cupolas, etc. Because of its flexibility and relatively low first cost, the electric industrial can fairly be called one of the most promising types applicable to a wide range of handling problems in the foundry.

The general utility of the electric industrial in foundry ser-

vice is due in considerable measure to its flexibility. Ability to work in close quarters, to handle a variety of materials, to carry loads horizontally over any route and vertically to heights of 6 to 10 feet, enable various modifications of this type of truck to fit into a wide range of operations.

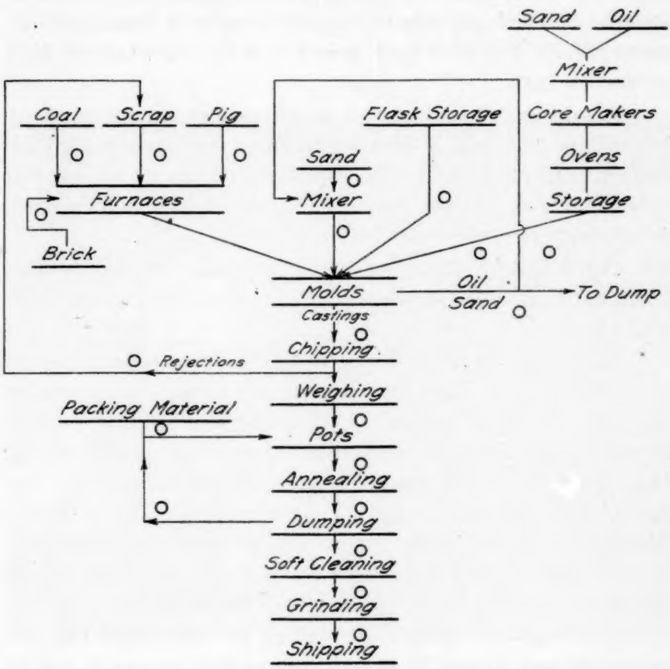


FIG. 1—FLOW SHEET OF MATERIALS IN A MALLEABLE FOUNDRY

Total Fixed Charges Low

The total fixed charge involved in operation of this equipment varies to some extent, depending upon working conditions and regularity of maintenance. Reasonably well cared for trucks operate at a total cost, including interest, taxes, depreciation, power and maintenance, of from 50 to 60 cents per hour. Life is

usually figured at from 7 to 10 years, but some trucks that have been in use for 12 years are still performing satisfactorily—as at the foundry of the Erie Mallable Iron Company.

The capacity of the 7 melting furnaces of this foundry is 250 tons a day, allowing a production of marketable castings of from 150 to 175 tons. Assuming that the figure of 168 tons of material handled per ton of castings shipped is reasonably accurate, 25,200 tons have to be moved in order to get out the day's production here.

For doing this work, a fleet of 14 two-ton, low lift trucks, 1 ten-ton lift truck, and 4 three-ton charging trucks are used. The two-ton trucks are assigned to practically all hauling except that of pig and scrap for the furnaces and that of handling annealing pots in and out of the annealing furnaces.

The flowsheet shown in Fig. 1 indicates graphically how many handling operations enter into the production of the malleable foundry.

Sand has to be moved from storage both to the core department and to the mixers that prepare it for the molders. Coal dust also has to be supplied to these mixers. Flasks must be handled in and out of the foundry as the types of castings change. Slag has to be carried away from the melting furnaces—in this case to a grinder that prepares it for use for packing in the annealing department. Following grinding, it is carried to the point of use. Burned sand is partly returned to the mixers and partly carried to the dump, along with other foundry waste.

The materials charged the melting furnaces, with the exception of coal, have to be moved from storage, located at various points about the plant. The castings must be removed, first to the chipping, inspecting and weighing departments; thence to rattlers and to the annealing department. From the packing stools the pots have to be moved into the furnaces, out again to the dumping floor, and then the pots have to be returned to the stools, or first to storage and thence to stools. Following annealing the castings have to be transferred to the grinding, sand blasting, straightening and finally to the shipping department.

Truck Has Wide Utility

One reason that has given the electric truck favor in the estimation of the management of this foundry, and of many others, is that this equipment offers a satisfactory means for the economical handling of the entire range of materials that have to be moved. The lift truck carries its load on skids and this makes possible handling bulk materials, scrap, brick, or castings with equal facility simply by the use of different bodies. For

FIG. 2—ANNEALING POT CHARGING IN A MALLEABLE FOUNDRY

the use of small malleable foundries an attachment has been devised for the low lift truck that enables it to move stacks of pots with entire facility, thus obviating the necessity for maintaining a special truck that might not be kept busy but a few hours during the week.

The regular pot charging truck, however, for operations in which it can function two or three hours or more a day, is more

efficient than the low lift modified as outlined above. At Erie four of these units are kept busy continuously when production is normal and as a consequence the savings that they effect are very large—amounting to more than 50 per cent over any other method that it had previously been possible to devise for accomplishing this work. This saving, incidentally, corresponds with the experience of several other users of this type of truck who have reported on results of operation.

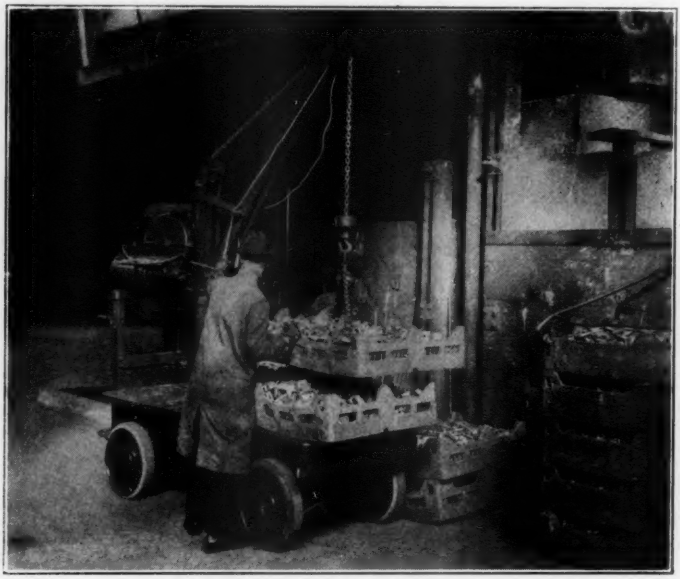


FIG. 3
SPECIAL CRANE ATTACHMENT ON TRUCK IN CLEANING DEPARTMENT

The four furnace chargers at the Erie Malleable average to pick up, haul and place 2500 tons of material every 24 hours. At a power cost of $4.00 a day these units are handling a tonnage equivalent to that transported by a freight train of fifty 50-ton cars. In a test run, the results of which have been verified by C. W. Cox, chief engineer of the plant, two operators with two of these trucks moved 900 stacks of pots weighing 3300 pounds

each. Of this number 480 stacks were transferred 300 feet and 420 stacks were delivered a distance of 80 feet in just 5 hours and 15 minutes. The trucks are able to enter the furnaces as soon as they have cooled to 600 or 700 degrees Fahr., and all of the pots can be removed before the heat is out. In this way it is possible to obtain increased capacity from them if need arises. Another point to be considered in connection with the use of this equipment is that no changes whatever have to be made in the plant to accommodate it.

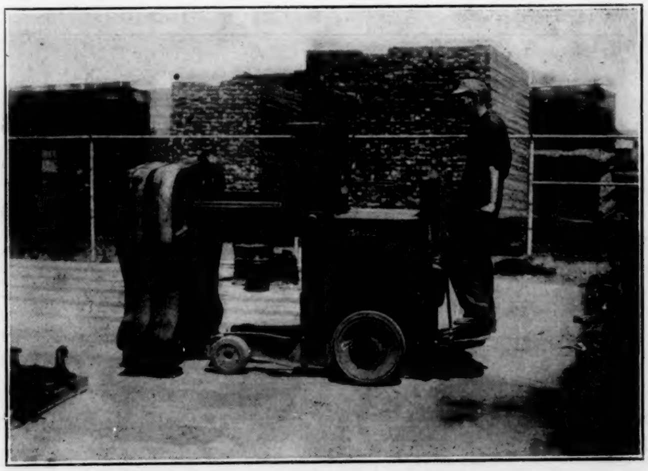


FIG. 4
SPECIAL LIFTING ATTACHMENT HANDLING BOILER SECTIONS

Saving Effected Is Large

The direct saving made by each of the lift trucks over manual methods is estimated to be worth at least $5,000 a year. In the chipping room 6 hand truckers and 4 weighers were required to handle the work; now one electric truck operator and 2 weighers working 2 hours a day conduct the same operations. Previous to 1919, when a truck was first assigned to this department, turnover was persistent because workers would not stick to their jobs. Since that time there has been no turnover what-

ever. This indication of saving effected does not represent an unusual instance of performances but merely points out how the truck fits into the handling scheme.

What are the problems involved in maintaining this equipment? Essentially these are reducible to two considerations, chassis upkeep and battery care. Under the first heading the essentials are consistent and thorough lubrication—preferably by the high pressure system—and at least weekly inspection by a mechanic who is competent to discover the need of repairs or

FIG. 5
SPECIAL LIFTING ATTACHMENT HANDLING TUMBLING BARRELS

adjustments. Battery care covers the proper use of charging equipment, periodic testing and cleaning. Simple instructions covering the use both of charging equipment and of batteries are provided by manufacturers of both of these types of auxiliary equipment and if these are followed, the probability of encountering difficulties in operation is negligible. Tire replacements are necessary at periods varying from once in four months to

once a year, depending upon the size of wheel and the nature of the runways over which the trucks operate.

Use for Charging Cupolas

There is perhaps little point in discussing the problems of the gray iron foundry as distinct from those of the malleable plant. The charging of cupolas frequently does present a problem, however, somewhat different from any that is encountered in the malleable foundry and for that reason a brief note on the present practice of one or two concerns using the electric for carrying these charging materials may be worth while. A modern organization, for instance, at its Chicago plant has developed a very modern layout for producing castings with a minimum amount of handling. From the bins that store the pig, scrap and coke on the ground level, electric trucks carry charges up to the charging level on an elevator, a haul not exceeding 150 feet. The trucks used are equipped with built-in scales so that the size of the load may be recorded without dropping the load on scales, backing away, and then picking it up again. The truck that is used for charging is of the self-dumping type, carrying skid loads up to the required height and discharging them as required directly into the cupolas. Formerly it was difficult, almost impossible, to keep workers on the job of charging, especially in the summer season, but by the use of the trucks (2 are employed in charging for 3 cupolas) this situation has been overcome successfully, and it is conservatively estimated that the direct labor saving runs from 4 to 8 men for the two units.

At the plant of the Long Island Foundry Company, located at Long Island City, N. Y., the charging floor is approached by a short steep ramp running up from ground level. This ramp is 40 feet long with a grade of 15 per cent. The trucks that are used for general purpose handling around the foundry take care of all of the material charged. One 1-ton truck and one 2-ton truck have been used since 1920 and have consistently demonstrated a saving of 4 men apiece. The first truck was purchased when wheelers were receiving $48.00 a week and is known to have paid for itself in the first ten weeks of operation.

Although such an experience in paying for this equipment

out of savings may be representative of better than the average, it has become clear from a study of operation in many foundries that the electric pays for itself completely in from 6 months to a year of operation, at the outside.

The use of the electric lift truck for ladle carrying demonstrates a very practical application of this equipment. One of the foundries of the United States Radiator Company uses two trucks in this way. By releasing overhead crane equipment for other jobs, it has been found possible to increase the capacity of

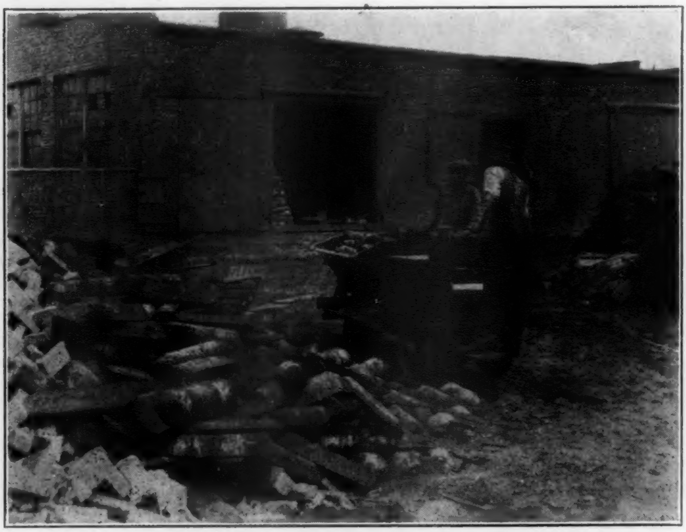


FIG. 6—DUMP BUCKET ATTACHMENT HANDLING PIG IRON TO FURNACES

the foundry by 30 per cent. The American Seating Machine Company has replaced an industrial railway system with 5 trucks that run off a 40 ton heat in 3 hours. No slopping has been experienced and the method is considered thoroughly satisfactory.

When trucks are used entirely in such service as handling green cores in and out of ovens, the fixed charges are a minimum because working conditions are relatively ideal. The opportunity for saving the expenditure of unnecessary work in this opera-

tion is clear; the racks for the green cores are placed directly alongside the core makers and after baking, the cores are either left in the racks till required or are transferred, a tray at a time, to storage. Breakage is decidedly decreased.

The handling of cores frequently presents one of the worst problems faced. One foundry that had to move cores from the fourth floor of the making building to the molders' benches, 1,000 feet distance, tried out several methods of handling with

FIG. 7—CRANE AND MAGNET ATTACHMENT HANDLING PIG IRON

but scant success. The nearest-to-adequate solution was found in hand truck handling, 2 men to a truck carrying 2 trays of cores at a time. Six men were thus occupied while 2 others were kept busy distributing in the foundry, thus making a total of 8 engaged in this work.

When electric trucks were introduced in the plant, a special spring suspended trailer was developed for carrying the cores. By making this change it was found possible for a tractor driver with one helper to move the entire day's supply of cores to the

foundry in less than an hour. The services of one man are now required for distribution to the benches. Only 10 man-hours are required now for a job that formerly required 72.

In this same foundry, a job is done with the electric that illustrates the range of its utility. Formerly when the bottom of the cupola was pulled in the afternoon, 20 men had to be taken from other work, to pull the cable attached to the pan under the cupola. At least five minutes was always required for the opera-

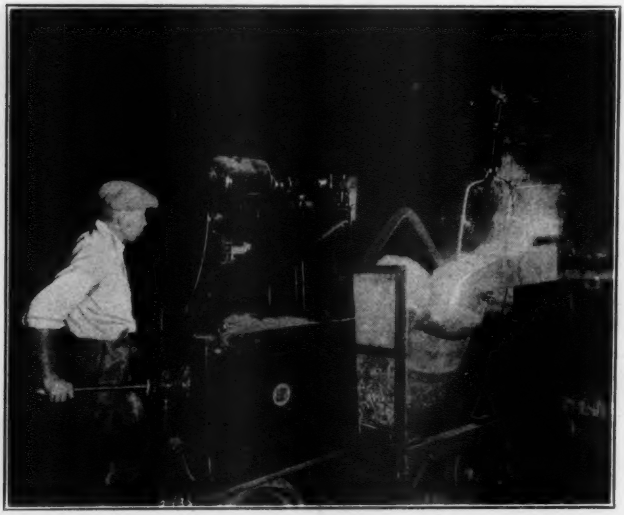


FIG. 8—BUGGY LADLE ATTACHMENT ON TRUCK FOR HANDLING IRON FROM CUPOLAS TO FLOOR

tion, sometimes more. Now the operation has been made part of the regular routine for one of the foundry electrics which is used in place of the 20 men. The job now requires only a couple of minutes.

Because comprehensive cost figures on the benefits to be derived from handling material with power equipment give a better key to savings than isolated instances of performance, the following tabulation of the "before and after" cost data on a plant principally involving foundry operations is significant.

In concluding this presentation of the performance of the electric industrial truck in foundries, two or three points should be made that are especially important but which are in no way indicated by the above figures. Labor turnover is a very definite "liability" which any type of equipment that eases the heavy jobs tends to reduce. In the foundry finishing operations, idle time on the part of operatives or machinery is expensive—a power system of transportation obviates the necessity for tolerating it. Congestion, like labor turnover, must be regarded as a liability, lowering production and interfering with steady production—especially when the foundry is being pushed to peak capacity.

Table 1

CAPITAL INVESTMENT	
Equipment	$22,000
Improvements	5,000
OPERATING COSTS (PER YEAR)	
Labor—Before electric truck installation	$99,716
Labor—After electric truck installation	32,242
Maintenance and depreciation on equipment (20 per cent)	5,400
Total annual saving	62,074
Per cent return on investment	229

FIG. 9—DUMP BUCKET TRUCK HANDLING REFUSE MATERIAL AND SAND

Prompt movement of materials, as rapidly as they are in shape for succeeding operations, not only decreases congestion, but when it is properly organized, eliminates it altogether. It has been shown to be possible for this decrease in congestion to promote increased production in an area and with facilities that apparently preclude such a possibility.

When Andrew Carnegie was building up the properties that have made him famous, it was his practice to replace any method

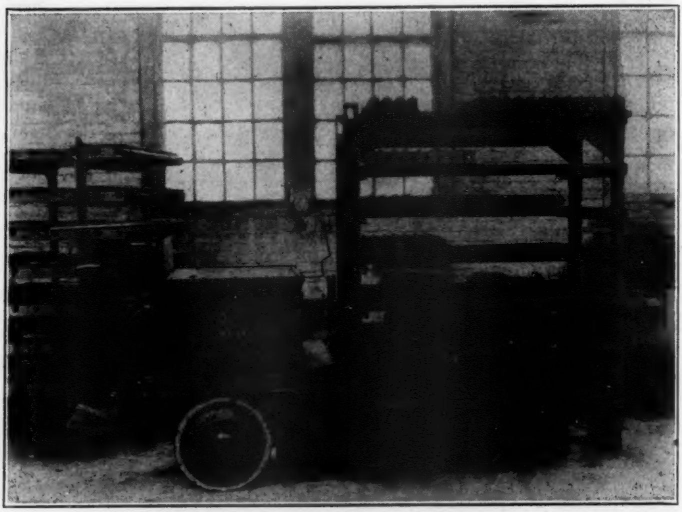


FIG. 10—TRUCK HANDLING CORE RACKS

or any equipment as soon as something better presented itself. He is known to have scrapped millions of dollars in new machinery because he had found other apparatus, probably at greater expense, which he knew would reduce the unit cost of production and in time earn a larger return, even with the additional investment included. While Carnegie's capital was greater than that of most independent foundries, the principle to which he attributed a large share of his success holds as well for the small plant as for a huge enterprise—if anything, it is more important for the

small foundry to be equipped for economical handling than for the large one.

The trend to increase production per worker is marked at the present in every industry. In foundry practice, as in industrial practice, there is no question that one of the most promising opportunities for achieving this end lies in improving methods for material handling. Such improvement is the logical sequence of installation of power equipment capable of aiding the hand trucker or wheel barrow pusher. As such a type of equipment the electric industrial truck, in its various modifications, merits close consideration and if the opinions of present users may be accepted as a criterion, then the electric may be adjudged a success in meeting most problems of foundry handling.

Finally, one word on the part played by the Society for Electrical Development in preparing this account for your consideration. The function of this organization is not to sell, for the most excellent reason that it does not manufacture equipment of any kind. Rather its object is to fulfill the need for supplying unbiased information on such questions as those here discussed. If, in such capacity, the society can be of service to any of you individually, its staff will be pleased to hear from you directly. Communications addressed to this organization, at 522 Fifth Ave., New York City, will receive prompt consideration—this service is yours for the asking.

Discussion

P. F. Nydegger: At our plant we have the problem of electric truck handling of skids for very short distances, a question of a few feet. I would like to ask whether or not this rolling skid is already a standardized product? We have evolved three or four trucks that way that can be handled, rolling skids as I would call it, but not for anything heavier than about 1,000 or 1,500 pounds.

Now, in machine operations, where the electric truck covers quite a territory, for a machine operator it is nice for the operator if he can just take that skid and push it 10 or 15 feet. And perhaps for some operations a lift skid at an increase of perhaps treble the price over what I would call a stationary steel skid is something that will have a large application in the future. I would like to know if any such skids have already been manufactured that will stand up. We would look for a capacity up to about two tons, no heavier.

H. J. PAYNE: Such a skid can be obtained and such a skid is being used at the present time, and for short hauls, where your ground conditions or your floor conditions are reasonably decent, there is no reason why it can't be worked out practically.

E. S. COHEN: May I ask a question with regard to the use of the battery operated truck for handling hot metal. We have two of them.

H. J. PAYNE: I will grant you that that operation probably would not be designed as a standard operation. That operation it is also true, as you just brought out, was to help the foundry developed thirty years ago to get its costs down. I happen to know that in one foundry where that system is used the crane capacity has been increased 30 per cent by taking off that part of the crane load.

E. S. COHEN: The operation of lift trucks or battery operated trucks of any kind handling metal is dangerous, to begin with. Can these trucks be used for handling hot metal?

H. J. PAYNE: It is dangerous if your control is not adequate, if your load is not under absolute control every second, I grant you.

E. S. COHEN: It requires extra supervision.

H. J. PAYNE: No! Ordinary workman can do it.

E. S. COHEN: What I mean is, they must be supervised by someone. The ordinary workman in the foundry handling metal must have supervision.

H. J. PAYNE: You are getting down to a discussion now where I have to say more for the electric truck than I would like to say, but the smoothness of operation made possible by storage battery trucks has absolutely obviated that particular difficulty that you bring up, that you would fear. It is used in at least half a dozen foundries that I know a good bit about, so far as that operation is concerned.

E. S. COHEN: We operate about 30 tractors, part gas and part electric, and part of them lift trucks. Our experience has been that if we could do it otherwise, we would eliminate the lift truck, because their maintenance cost is very high. We have kept them because we haven't found anything to take their place thus far.

H. J. PAYNE: Well, that is encouraging. The cost of maintenance alone, forgetting the items of depreciation and interest, which I presume is the cost that you speak of, depends 100 per cent on the supervision and the regularity with which the equipment is gone over by a mechanic. At Erie—I go back to that because it is an outstanding installation—they have trucks in service that have been there for 14 years and their maintenance cost there is below the figure that I quoted. It is always a question with

any type of equipment, material handling or otherwise, on maintenance cost, as I see it, as to how it is supervised and how regularly it is gone over.

E. S. COHEN: We have a special department that has nothing but that to care for.

H. J. PAYNE: How high have your maintenance costs been?

E. S. COHEN: I don't remember the exact figures offhand, but I know our attention was called to it a short while ago when we were considering the installation of gasoline lift trucks for getting the racks into the oven.

CHAIRMAN B. D. FULLER: Is the chief item in that maintenance battery, or is it something else? That has been my experience with trucks of similar kinds.

E. S. COHEN: The battery is the big item, because the battery is so very expensive. That is why we would rather run on direct current generated from the illuminating company's office than from a battery hanging on a truck.

H. J. PAYNE: I don't know how you are going to measure the actual cost of battery maintenance. If you measure it in terms of life, it is true that a lead battery, perhaps, has a limited life, to the extent of three years, or three and a third, and a nickel alkaline type has a life of five to seven years. Now, in foundry work I have found that in most cases the batteries exceed that minimum, and if that is so and the supervision is reasonably adequate, I can't see that your battery cost itself would be excessive.

Apprentice Training Results Secured by a Lecture Course and Supervision

By P. R. Ramp*, Newport News, Va.

While the apprentice boy is a workingman, his mind, because it is fresh, is ready to be bent in the right direction, or it is ready to be twisted in the wrong direction. Therefore, it is directly charged to the foremen of a shop whether or not their future molders and their future pattern makers are to be good or bad, according to the way they, the foremen, handle the situation.

Adhering to the principles, pursued by our educators throughout the country, that a person can learn more rapidly by using the methods of seeing and hearing at one and the same time in learning, we have established a lecture course for all of our foundry and pattern shop apprentice boys. These boys convene in a special lecture room for a demonstrative lecture, on the different phases of their work, every Wednesday afternoon forty minutes before quitting time. This group is pictured in Fig. 1.

The big problem is to formulate plans which will result in the maximum amount of learning the boys can accomplish in the minimum amount of time; so it is up to us to study just what they need most at any particular time. Knowing this, we can give them the greatest amount of help. For instance, we may discover that there is an epidemic of bad castings. The defective castings of the epidemic may be due to the gating, ramming, clamping or coreing up of the molds.

If improper gating is causing the loss, we demonstrate the correct procedure in remedying these defects by making a mold and cutting the gates, and explaining in detail the why. The result is amazing in many instances, and even though only fifty per cent of the boys in the class may absorb the content of the lecture, we know that there is a great saving effected by the

*Foundry Supt., Newport News Ship Building and Dry Dock Co.

fifty per cent which absorbs the information given. Consequently, I believe that to see the work properly done and to hear from an experienced foundryman why it is done is worth more to an apprentice boy than the reading of ten volumes on the subject.

In a foundry where standard work is being done at all times, perhaps it is not necessary to have as many lecture hours as we do, but since our work is so diversified, it is highly important in respect to costs to instruct each boy in the way new methods are making it possible to obtain cheaper and better castings, instead of letting him learn how the old molder is doing it with his methods which were employed by our forefathers.

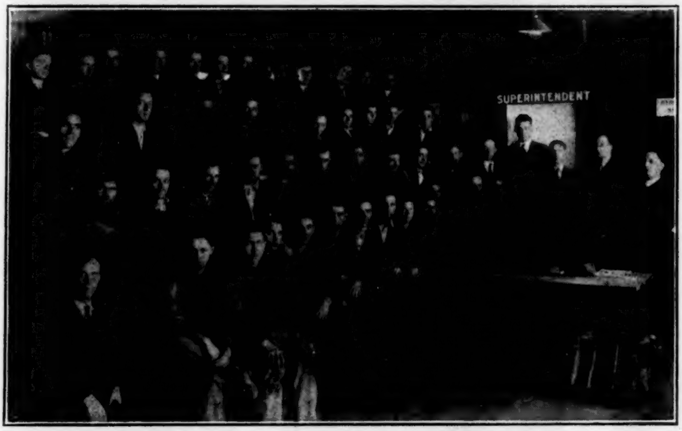


FIG. 1

What some foundries need today is that new blood, bringing with it those new methods which are the result of time study, science and invention. They need molders who know exactly why they do a thing, and when to do it. They need men who regard their craft as a profession, the knowledge of which renders their work an art, leaving an industrial monument to their fellow workmen emblematic of that knowledge.

FIG. 2

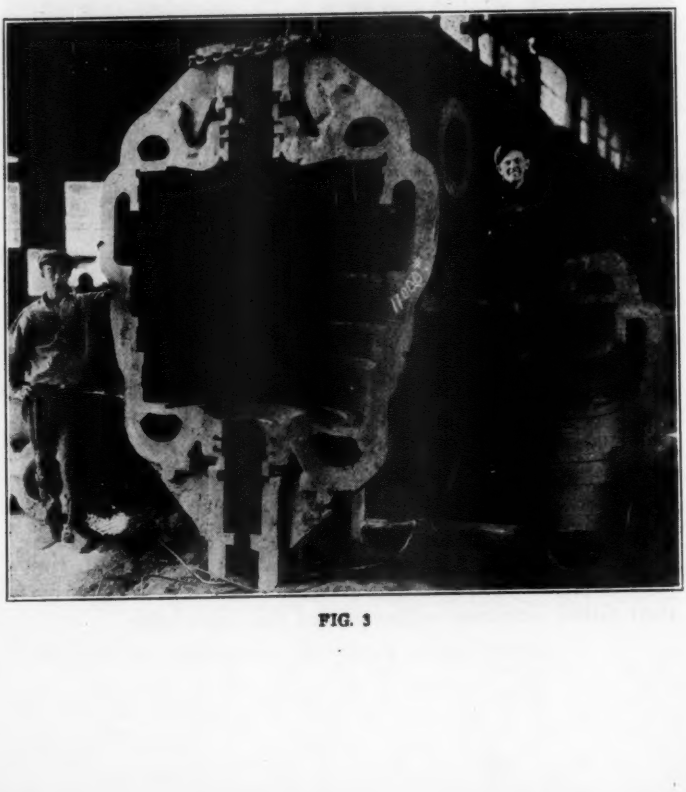


FIG. 3

These statements are not based on theory merely, but on the results of theory and practice in our foundries and pattern shop.

Results Secured in Making a Low Pressure Turbine Casing

In teaching young men how to mold, we do not simplify the methods in order to make it possible for them to do the work, but because we want to teach them the best and the cheapest methods. We would not make much progress if we taught a man how to make a mold in the same manner it has been made during the last forty years, if there were a better and a cheaper way to do it. For this reason we spend a great deal of time deciding upon the very best practice before attempting to teach the apprentice boy how to do it.

A good example of what young men can do, if properly instructed and encouraged is illustrated in the following.

We had been making turbine casings in loam for a number of years. It required three weeks and sometimes longer to get one of these molds ready for the oven. We built a flask, made some alterations in the pattern, and taught two apprentice boys how to ram and finish this mold ready for the oven. As a result of the improved method and the young men's enthusiasm, they did the work in three and one-half days instead of three weeks. Fig. 2 is the mold finished ready for the oven, also showing the two young men who made it. The ramming and finishing of this first mold was supervised by a foreman who was qualified to teach the boys every detail. He was a good mechanic himself, and best of all, he believed in boys and apprentices. Fig. 3 is one of the castings made from these molds with the two young men who made it.

For us to say that these boys are proud of what they have accomplished, and that they love their work would be putting it very mildly. We claim that while the improved methods with the new equipment were advantageous, the foreman who believed in ability of the boys was directly responsible for their success and for their attitude towards their work.

The cores for these molds were of a very intricate character, and they had always been made without any consideration of

modern methods. Consequently, it required a first class coremaker of the old school to make it. In order to improve this condition the large cores were cut into smaller pieces, and the proper division made in the more difficult ones. The result was that the entire set of cores were successfully produced by apprentice boys. When the first set was made half of the cores were scrapped and made over, and the other half were none too

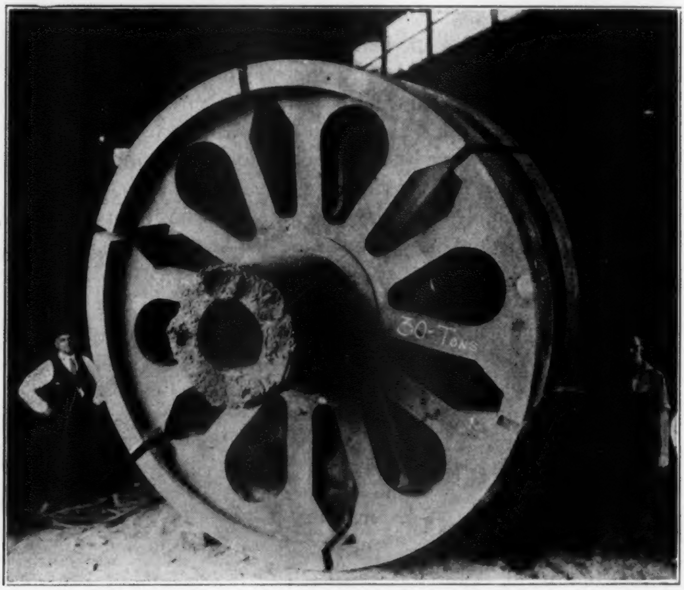


FIG. 4

good, but the second set and all following sets were first class cores produced at a much lower cost than by the old method. This was made possible by creating a spirit of enthusiasm in the young men doing the work.

A Thirty-Ton Gear Center Casting

Teaching the boy the *why* of molding is what gets results in the jobbing foundry. If care is exercised in selecting these

young men it will be found that it is not necessary to let them linger along in the A B C of molding. The plan of allowing the apprentice boy to help around the shop for a period of years to enable him to become familiar with details before he begins to mold, and the keeping of him on simple work for several months is wrong. If the boy is going to make a mechanic, if he has the stuff in him, we should work fast if we are going to get him not only interested, but enthused in the work.

The idea that we can advance the boy too fast originated with the foundrymen who did not have the time or inclination to teach a boy details connected with the making of difficult castings, and was content to let the apprentice drift until he had served four years at molding, and then demand a day's work for a molder's pay. The consequences were that the four years of apprenticeship was almost wasted unless the boy was exceptional.

Fig. 4 is of a thirty-ton gear center for a large passenger ship. The young man on the right is an apprentice boy who was taught the *why* of molding. He made the loam mold, put it in the oven to dry, placed the cores, closed the mold, made the necessary runner basins and riser heads, and assisted in pouring. There was not a blemish on this, nor on others which he made. This young man has been working less than three years at molding, or foundry work. This is more evidence of what *job analysis* or *intensive teaching* will do.

Loam Molds Made by a Youngster

A good illustration which helps to prove that detailed instructions make the usually considered difficult molds simple is shown in Fig. 5. This young man is shown sweeping up a loam mold for a condenser cover. He is not helping the molder do it or carrying the brick; he is doing it alone. It has been proven that the quicker we put the boy to working alone the quicker we get results, the faster he grows in ability, and best of all, the more he loves his work. This young man has been in the foundry for about six months, and he has, in several instances, done a bigger day's work than some journeymen.

Pattern Shop Apprentices

We have twenty-two apprentices in our pattern shop, with only a few who have worked more than one year making patterns. Regardless of this fact they are able to produce large, difficult patterns sometimes at a lower cost than the same patterns were made previously by journeymen patternmakers. The reasons we believe that we have been successful in this undertaking

FIG. 5

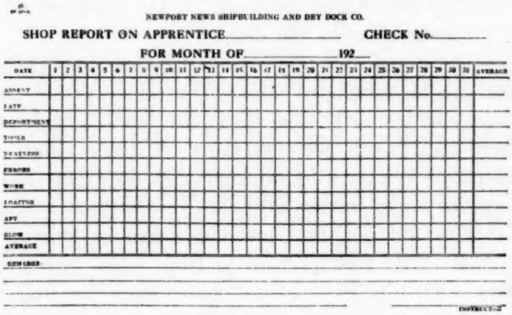
is because the young men have been taught the *why* of everything they do. This makes it possible to produce a high grade mechanic in a much shorter time.

The old plan of spreading the boys out among the journeymen and letting them absorb what they could in a course of four or five years does not bring very good results. The trouble is that while they are absorbing some of the fundamentals from these old men, they are at the same time, probably unconsciously, learning how to beat the boss, and learning to consider him as their enemy rather than their friend.

In the shop it is sometimes amusing to hear an old mechanic refer to another workman in this manner: "Oh, he is only a handy man," when the fellow referred to has probably worked at the trade for ten years, and the only difference between the two is that the second started as a handy man instead of an apprentice. The only reason the old fellow likes to hang this name on him is that it is one more attempt to discourage apprenticeship.

Apprentice Records

In our pattern shop we have what is termed "A Monthly Report on Apprentices." This is shown in Fig. 6. From daily information of this report the apprentice boy is given his monthly


NEWPORT NEWS SHIPBUILDING AND DRY DOCK CO.

SHOP REPORT ON APPRENTICE________________ CHECK No.________

FOR MONTH OF______________192__

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	AVERAGE
ABSENT																																
LATE																																
DEPORTMENT																																
TOOLS																																
NEATNESS																																
ERRORS																																
WORK																																
LOAFING																																
APT																																
SLOW																																
AVERAGE																																

REMARKS:

INSTRUCTOR

FIG. 6

average. This average is made up as follows: For being absent he is charged four points; for being late, two points; deportment, two to four points; tools, two to four points; neatness, two to four points; work, two to four points; slow, two to four points; loafing, two to four points; apt, two to four points.

Every day each boy's card is marked up according to his performance. The item tools refers to how sharp or how clean they are; neatness, the condition of his time cards, his bench, and his personal appearance; errors, refers to mistakes in his work; work, means the quality of the pattern he produces; loafing, is visiting with other boys; apt, is the manner in which he absorbs instructions; slow, means below the average workman. These reports create a great deal of interest as this percentage

is posted in the shop monthly, and the boys watch for the report and often fight for what they consider their just dues. If they have a good average, they go home and tell their parents about it.

We also have the boys' work benches numbered. The boy who has the best average and is making the most progress is entitled to work at bench No. 1, or have his own bench numbered one; the boy next in line is entitled to bench No. 2, and so on down the line. This also has a tendency to make the boys strive for a low bench number.

Training apprentices is not always a bed of roses, especially in the old established shop. Someone has said that the day of the skilled mechanic is past. This is a mistake; the only difference is that the day has come when it requires much shorter time to develop the skilled mechanic by the adoption of modern methods of instruction in the shop.

Some are under the impression that the only place where mechanics can be developed who can produce good patterns or good castings in a shorter time than four years is in the specialty shop where their work becomes more or less a habit. This is also a mistake. We have found, that with the right kind of men instructing the young men in *why* they do things and *what* would happen if they did not, that mechanics can be trained for the jobbing shop. The best plan is to train your own men to be instructors. This gives you an opportunity for selecting the men with the proper temperament for the work.

Report of Committee on Corrosion of Metals

To Members of The American Foundrymen's Association:

Your committee on Corrosion of Metals has held several meetings during the past year. A meeting of the committee was held on Sept. 8th, 1926, at the Bureau of Standards in Washington and opportunity was taken by members of the committee who were present to inspect the four year soil corrosion specimens which are now being re-weighed and measured for depths of pitting, etc.

Inasmuch as the chief interest of your committee has centered on soil corrosion, a sub-committee, consisting of five representative members, has been organized and is charged with publishing the forthcoming data on the soil corrosion specimens as soon as the records are completed. This is expected to be about sixty days from the present date. The information will be published by permission of the Director of the Bureau as a progress report, and will be similar to the first progress report published in 1924 and now appearing on pages 144 to 166 of the "Proceedings of the American Foundrymen's Association," Vol. XXXII, Part 1. Copies of both progress reports may be secured by addressing the Secretary of the American Foundrymen's Association.

While your committee is unable to draw any conclusion that would be final from the inspection of the specimens that have been in the soils of forty-six localities for approximately four years, yet several matters of general interest might be reported at this time.

Only four of the soils in the forty-six localities have any markedly severe corrosive effect on the cast iron, cast steel and malleable cast iron specimens, and of these commercial foundry products, there is little if any difference so far in their respective behaviors in any of the four corrosive soils. The corrosion products on all three grades of foundry specimens had the same general appearance. The oxides occurring on cast steel and malleable castings have the same cellular appearance as the so-called but mis-named "graphitic" oxidation on cast iron.

After burial for four years, the three specimens of cast iron pipe which had been welded by means of Tobin bronze showed no appreciably greater pitting or deleterious effect due to the super-imposing of bronze upon cast iron. The effects of soil corrosion on various welded joints is deserving of very careful study and should be of considerable interest after sufficient data is compiled to draw conclusions.

Specimens of de Lavaud centrifugally cast iron pipe showed less severe pitting in the worst soils after the two and four year periods than did ordinary sand cast pipe. It was of interest to note that the pits on the exterior of the de Lavaud pipe were not as deep as those on the interior surface.

The committee is also interested in learning whether or not castings which have their original surfaces machined off to a depth below the so-called "skin" show greater or less losses from pitting; but, clearly, the four year period is not sufficient time to reveal any data of interest on this particular point. This matter, however, will be carefully checked and reported upon in subsequent inspections. Similarly, it was clear to those present at the inspection that sufficient time has not elapsed to learn whether or not any difference can be measured between the effect of soil corrosion on so-called "close-grained" castings and "open-grained" castings.

The committee has recommended that a supplementary study be made by our sub-committee on Soil Corrosion in conjunction with the Bureau of Standards of existing pipe lines buried for known periods of time in at least six locations of the United States where the soil surrounding the pipe line will have been identified as being identically the same as one of those now being used for testing the specimens. In other words, the data thus forthcoming from existing pipe lines will serve as a check upon observations made by means of the present field and laboratory tests that will continue for several years.

As an additional check on this work, the committee also has recommended that four or five severely corrosive soils out of the forty-six localities be selected for the burial of new specimens. The new specimens will consist of the same commercial products as those buried in 1922 (four years ago) and will serve to make

available a larger amount of comparative data in the most interesting of the soils that are being investigated. The committee likewise recommends that one or two of the more widespread or typically less corrosive soils be selected for the burial of additional specimens so that an ample amount of comparative data will be available and serve for checking purposes.

Your committee wishes to express its thanks at this time to the officials of the Bureau of Standards for the excellent co-operation and service that is being rendered to American business and industry.

Respectfully submitted on behalf of your Committee on Corrosion of Metals.

H. Y. CARSON,
Chairman.

Preliminary Report of the Subcommittee on the Survey of Conditions in the Malleable Industry

Introduction

The making of malleable iron castings is a large industry today, not only in the United States but in Canada and other foreign countries as well.

The process of making malleable iron requires extensive furnace equipment. The reverberatory furnace is still the most popular type of furnace equipment for melting the charge for making the white iron castings, although cupolas, open hearth furnaces and electric furnaces are used to a limited extent in the production of castings. After the castings are poured off, it is necessary to subject them to a long annealing cycle in annealing furnace equipment in order to malleablize them and produce the physical properties and requirements necessary for commercial use. Auxiliary furnace equipment used in the production of malleable iron are core ovens and ladle dryers.

The process, as a whole, is rather complicated and there are many variables involved both in materials used and practice. Also the human element plays an important part in the process of production of malleable iron castings. Improvements in methods and equipment employed in the malleable foundry have been slow. However, within the last few years some foundries have modernized their practice to a great extent. A study of the conditions in the malleable iron industry with regard to furnace equipment and their attendent refractory problems reveals a great diversity of practice and results obtained.

The committee in reviewing the conditions in the industry have gone a little farther than perhaps was intended they should

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The Joint Committee on Foundry Refractories is sponsored by the American Ceramic Society and the American Foundrymen's Association. In addition to these two organizations the following are represented and are cooperating in this work: American Refractories Institute, American Malleable Castings Association, American Electrochemical Society, U. S. Bureau of Standards, U. S. Bureau of Mines, Division of Simplified Practice of the U. S. Dept. of Commerce, Steel Founders' Society of America, Electric Steel Founders' Research Group and the Institute of Metals Division of the A.I.M.E.

in pointing out the more common faults in need of correction, not so much as they refer to the quality of refractories but in the use and abuse of refractories as resulting from poor practice.

Electric Melting Furnaces

Electric melting of malleable iron is a comparatively new venture, although a few foundries have been operating electric furnace melting equipment for several years. This is particularly true of the duplexing and triplexing operations which employ electric melting equipment for superheating and refining.

Within a few years electric melting of malleable iron from cold charges will undoubtedly be very extensively used and reference to the refractory problems encountered should be made at this time.

It is the thought of this committee that the refractory problems of the users of electric steel melting furnaces running with acid linings would coincide with the problems the malleable foundries operating electric equipment would have. However, the making of malleable in the electric furnace is somewhat easier on the refractories than steel making is. Therefore, it is recommended that the report of subcommittee on the survey of conditions in the steel castings industry in so far as it refers to acid lined electric steel furnaces applies to the electric malleable furnaces.

Open Hearth Furnaces

A few open hearth furnaces for melting malleable iron are operating. It is the recommendation of this committee that inasmuch as the steel industry is a large user of open hearth equipment, the subcommittee's report on the Survey of Conditions in the Steel Casting Industry be applied in so far as it relates to the acid lined open hearth furnace problems of the malleable plants.

Cupola Equipment

Considerable cupola malleable iron is made now, particularly amongst pipe fittings foundries. Probably more cupola malleable will be made in the future because considerable attention is being given to improving the quality of black heart malleable made from

iron melted in cupolas. Improvements in physical properties of cupola malleable are being made right along and, therefore, it should find a place in competition, to a certain extent at least, with reverberatory furnace process. Inasmuch as the melting of iron in the cupola employed in the process of making malleable iron is practically similar to the ordinary cupola operation of making gray iron, the Subcommittee's Report on the Survey of Conditions in the Gray Iron Castings Industry will cover the refractory problem fully without making it necessary to duplicate the work.

Reverberatory Furnaces

The great bulk of the white cast iron used in making black heart malleable iron today is melted in the acid lined reverberatory furnace or so-called air furnace, and it is on this particular equipment that the committee concentrated its efforts with regard to analyzing the conditions.

From the rather elaborate questionnaire sent out by the committee 41 per cent returns were received. These questionnaires covered reports on 181 furnaces, representing a total melting capacity of 3,475 tons, of which 56 per cent were hand fired, 41 per cent pulverized coal fired and 3 per cent oil fired.

General Description: The reverberatory furnace is in general a long narrow furnace, the side walls projecting considerably above the hearth to support the removable bungs for charging and repairing. Rear and front bridge walls hold the metal bath on the hearth. A fire box is located on the front end of the furnace, the products of combustion passing over the front bridge wall and over the bath of iron to the stack back of the rear bridge wall. Forced draft is used under the fire box grates to increase the combustion of gas coal used in firing. Secondary air is supplied through the bungs over the front bridge wall to aid in complete combustion of the gases. Proper firing and manipulation of the blast gates are essential for efficient results, both in fuel rates and in the life of refractories. Molten metal is tapped from the sides of the furnace at the lowest levels of the hearth.

In the case of the pulverized coal fired and oil fired furnaces, the front bridge wall is done away with, and the hearth sloped up to the front wall and the fuel applied from the front end wall.

To convey some idea of the amount of refractories used in building reverberatory furnaces, we cite an example of a typical 20 ton hand fired furnace with 13½-inch walls, a 4 foot diameter stack by 70 feet high. A furnace of these general proportions will use approximately the following quantities of fire brick refractories.

Furnace side walls, etc............	6500—9-inch straights
Bungs	1300—13½-inch bung brick
Stack	9100—circle brick
Furnace bottom....................	3 yards sand
Fire clay for laying up brick........	2.85 tons

The cost of this amount of refractories, Chicago base price, is about $954.00. This does not include labor of laying nor furnace structure.

White cast iron melts in the neighborhood of 2350 degrees Fahr. The amount of superheat required before it is ready to tap depends a little on the general class of casting being made in the foundry. If light sections prevail in the castings, the iron must be hotter than if heavy sections are poured off. Also if bull ladles are employed to convey the iron to the molding floors the iron must be very hot in order not to be too dead when it is finally poured into the molds via the hand ladles.

The proper temperature of the iron in the furnace when ready to tap varies between 2700 and 3100 degrees Fahr., depending on the class of work being handled. The temperatures of the furnace gases will be higher by 100 to 200 degrees Fahr. Therefore, it must be realized that the maximum temperatures prevailing in reverberatory furnaces are approaching the softening point of first quality fire brick. First quality fire brick of approximately 51 per cent silica and 40 per cent alumina will begin to soften at about 3100 degrees Fahr. and will drip and run at 3250 degrees Fahr.

At the best, the reverberatory furnace is a very inefficient piece of equipment—about the poorest used in metallurgical work.

Investigations and answers to the questionnaire indicate a wide range of results and operating methods for reverberatory furnaces. Malleable operating men appreciate the difficulty of duplicating good results obtained on one furnace in another that is not giving satisfactory operation.

General Conditions Affecting Reverberatory Furnace Operations: In general too little attention has been given to the proper proportions of design in reverberatory furnaces. Proper heights of bridge walls with relation to the hearth and bungs are necessary. Proper application of the secondary air over the front bridge wall is necessary, both for fast melting of the metal and long refractory life. Proper stack draft and means of controlling stack draft influence the operation of the furnace and life of the refractories. Proper placing in the furnace of all material making up the charge is very important for good results. Too little attention is paid to properly firing a furnace. This is particularly true of the hand fired equipment. Instead of firing at frequent intervals in small quantities, fire boxes are many times heaped up, thus making for a poor operation. A great deal of improvement could be accomplished if furnaces were equipped with carbon dioxide recording and indicating instruments and firemen trained to intelligently fire and adjust the furnaces accordingly. Many furnaces are unnecessarily abused by laborers not exercising care in the handling of bungs and the placing of the charge in the furnace. Improperly making furnace repairs contributes to the short life of refractories. In general, the human element is responsible for many of the troubles encountered in reverberatory furnace operations.

Spare Furnaces

There is one thought the committee would like to impress upon reverberatory furnace operators, and that is that most malleable foundries do not have spare furnaces and hence must repair their furnaces every week-end or every second week-end, as the general efficiency of their operations and life of the refractories dictate. It is surprising the great number of reports that indicate repairs to side walls, furnace bottom renewals and new bungs every 11 or 22 heats. Spare furnaces, if they can be afforded, would allow the foundry to operate their regular furnace until the maximum life was obtained from refractories. In many cases upwards of five or six more heats could be obtained before shutting down for repairs and swinging over to the spare furnace. A foundry with no spare furnaces, of course, cannot afford to sacrifice iron tonnage to repair furnaces during the middle of the week and must necessarily do it on Saturday and Sunday.

Hearth Bottoms

Hearth bottoms most commonly used are crude, washed and drained silica sand, crushed old fire brick bats, a combination of silica sand and crushed brick and lake or bank sand. Table 1 gives the life of such bottoms.

Proper preparation of the bottom has considerable to do with the number of heats obtainable. Improper use of the skimming bar spoils many a furnace bottom, again improper charging causes furnace bottom to break up and let the iron under it. Some foundries prefer to burn the furnace bottom in for an hour or so before putting it into service but they apparently obtain no greater life from the bottom than those that carefully tamp in the bottom, level it off and cover the new bottom with old pieces of cull lumber

Table 1

	Silica Sand	Silica Sand and Crushed Brick	Crushed Brick	Lake and Bank Sand
Maximum number of heats reported...	22	21	20	22
Minimum number of heats reported...	6	6	11	6
Average of all reporting..............	13	12	17	15

or old sheet metal sheets placed there to protect it from the initial charge.

The question of which material is best for bottom use will depend almost entirely on material prices in the immediate location of the foundry.

Front Bridge Walls

Front bridge walls in hand fired furnaces must be properly put in and tied into the side wall construction when built in order to insure that the metal will not break through them and get into the fire box. No great refractory problem is involved because the bridge wall brick work is well protected on the hearth side and top with silica sand usually thrown on after every heat.

The fire box side of the wall is, of course, subjected to the fuel bed and the fusion of ash and clinker against it. Too high a grate blast pressure may erode the face to some extent. Abuse through changing grates in the fire box causes considerable abrasive action at times. Rousting bars damage the brick work if carelessly used. Improper charging damages the hearth side of the wall.

In general, 9-inch straight, medium burned, first quality fire brick are suitable for the fire box face and the hearth side of the front bridge wall. The core of the bridge wall, can, if heavy enough, be cheapened by the use of second quality brick.

Front bridge walls should last at least a hundred heats with minor repairs to top courses of brick on the wall only at times of furnace repairs. Many foundries now only getting 50 to 65 heats can improve their practice. Some reports indicate as high as 150 to 286 heats obtained.

Rear Bridge Walls

Rear bridge walls do not present the problems in general that the front bridge walls do, provided they are well built and tied into the side walls. If proper combustion is taking place within the furnace proper, the temperatures of the gases are somewhat reduced by the time they pass over the rear bridge wall. However the top of the wall is subjected to considerable cutting action and erosion by the gases and repairs to the upper courses are usually necessary every time the furnace is repaired. Application of silica sand to the shoulders on the hearth side of the wall every few heats pretty well protects the brick work.

Second quality brick can be used in the core of the wall if necessary, but the outsides of the wall should be 9 inches straight first quality fire brick.

In general, at least a year's service should be obtained from a rear bridge wall if other conditions are right. Those who report only 40 to 80 heats are not getting the results they should. Some reports indicate two to seven years' service on rear bridge walls; others report indefinite life.

Furnace Stacks

When reverberatory furnaces are connected to waste heat boilers, the gases and products of combustion have been so reduced in temperature that by the time they pass into stack very little effect is made on the stack refractory linings and no particular problems are met. If, however, the boilers are cut out for any reason and the hot gases passed directly to the stack, then the

refractory problem must be treated the same as those furnaces operating at all times without a boiler.

In general, refractory life in a stack directly connected to a furnace is dependent on the capacity of the stack for handling the gases and also whether or not secondary combustion is taking place in the stack. Secondary combustion in the stack indicates very faulty furnace operation and should be corrected by all means. The checkered opening at the base of the stack should be used more in order to properly control the combustion within the furnace and, if the stack is of large enough proportions, considerable cold air can be admitted to cool the flue gases and thus favor the stack refractories.

In general, the stack should be lined with first quality refractories from the base a third of the way up. The inner face of first quality refractory lining can be backed up with a second quality next to the stack proper. The upper two-thirds of the stack should stand up indefinitely if lined with a single lining of second quality refractories. The lower inner lining should last one to two years, although some reports indicate as low as 40 heats. Others range from a year to an indefinite period.

We find the industry lining stacks with cupola blocks, circle brick, wedge brick, arch brick, 9 inch straights and various other shapes. For all regular conditions in the stack, 9 inch circle brick should be the standard size used for lining.

Fire Box Refractories

In the fire box of hand fired reverberatory furnaces the refractory problem is not so great as in the furnace proper, because maximum temperatures are not reached.

The three walls, like the fire box side of the front bridge wall, are subject to abuse from changing grates and the rousting bar. Clinker and ash fuse to the face about the bed of fuel. Constant opening of the firing door subjects the walls to repeated cold drafts, inducing spalling action. Blast pressure under the grates to supply the necessary air for combustion affects the life of the furnace side walls to some extent.

Table 2 shows the results now being obtained in the industry today.

Furnace Side Walls

The long side walls enclosing the hearth between the front and rear bridge walls are subject to number of destructive elements. The chief factors shortening the life of the side wall refractories are the cutting away of the walls at the slag line due

Table 2

Comparison of Grate Blast Pressures in Inches of Water With the Life of Fire Box Side Wall Refractories

Grate blast pressures in inches	1 to 5	5 to 10	10 to 20
Average number of heats reported	74	58	53

Comparison Between Fire Box Wall Thickness and Life of Fire Box Side Wall Refractories*

Thickness of walls in inches	9	12	13, 13½ and 14	17 and 18
Average number of heats for life of side walls	53	47	89	87

Comparison Between Life of Fire Box Refractories and the Quality of Burn of the Refractories

Quality of Burn	Soft	Medium	Hard
Average number of heats for life of side walls	77	100	62

Comparison Between Furnace Capacity and Life of Fire Box Side Wall Refractories

Furnace capacity in tons	Up to 10	10 to 15	15 to 20	20 to 30
Average number of heats for life of fire box	44	83	70	64

Comparison Between Life of Fire Box Side Wall Refractories† and Method of Laying Up Walls

Method of laying up	Dry	Daubed	Dipped
Average number of heats for life of fire box	35	64	67

*The furnaces with the thinner walls run about the same number of heats but must be patched more between renewals.

†Practically all foundries are using 9-inch standard first quality fire brick in the fire box construction, and there is no reason to recommend any change in this practice.

to impurities in the slag acting on the side walls, thus undermining the upper portions of the walls. Blast cutting and erosion of the sides is partially due to the top blast located in the wind bung over the front bridge wall, also the gases being forced between the charges heaped up on the hearth and the side walls cause erosion. Many times blast erosion can be reduced by the proper shaping of the tuyeres and reducing the blast. Improper methods of charging the furnace causes excessive abrasive action, although this cannot be helped altogether. Furnaces must also be charged immediately after a heat has been tapped out; hence the bungs are removed and the white hot side walls are subjected to sudden cooling action and spalling takes place.

Most foundries are using standard first quality 9 inch straights, soaps and splits in the side walls. A very few, however, use the large 9 inch straight. The committee recommends onlv the regular 9 inch standard straights, large 9 inch straights, soaps and splits for side wall use.

Over the skimming and sampling holes in the side walls the majority of foundries use No. 1 and 2 9 inch arch and wedge brick to make the arches. However, quite a few foundries are using large tile brick over these openings with good results. This practice is to be strongly recommended because it is an easy job for the brick layer to lay a tile where it takes longer time to set an arch. Of course, a variety of tile sizes are now used and most of these are purchased on a higher cost basis than the 9 inch equivalent. The committee recommends that standard tile be adopted for this work in two sizes, viz: 5 inch by 9 inch by 24 inch and 5 inch by 13½ inch by 24 inch. These thicknesses correspond with the standard 9 inch brick, the widths work out for varying wall thicknesses and the length will span any hole opening.

Side walls are usually patched before a complete overhauling. This patching is usually accomplished by cutting away the glazed surface of the spots eroded away and either inserting new brick or brick bats with a generous daubing of fire clay.

An interesting table (Table 3) has been made up from the recorded experiences of many foundries in the industry and should be of considerable help in working out satisfactory specifications for side wall brick.

From some of the foregoing summaries of Table 3, it is evident that none of the three methods of firing have any decided advantage from standpoint of greater refractory life on the side walls. Comparing the pulverized coal fired and the oil fired furnace combustion chamber wall life, which is a part of the side walls, with the fire box end of the hand fired furnaces, it is found that the hand fired box averages 87 heats against 47 heats in the pulverized coal furnaces. Not enough figures are available on oil fired furnace combustion chambers to attempt to make an average, although it would be expected that it would average up with the pulverized coal fired furnaces.

Table 3

Comparison Between Top Blast Pressures in Inches of Water and Life of Side Wall Refractories*

Top blast pressure in inches	1 to 5	5 to 10	10 to 20
Average number of heats for life of side walls	22	22	30

Comparison Between Side Wall Thickness† and Life of Refractories

Thickness of walls in inches	9	12	13, 13½ and 14	17 and 18
Average number of heats for life of side walls	24	18	27	23

Life‡ of Side Wall Refractories Compared With Causes of Greatest Trouble

Greatest trouble causing failure	Slag Action	Erosion	Abrasion
Average number of heats for life of side walls	25	23	35

Comparison Between Life of Side Wall Refractories and the Quality of Burn of the Refractories and Causes of Greatest Trouble

Greatest trouble causing failure	Slag Action			Erosion			Abrasion		
Quality of burn	Soft	Med.	Hard	Soft	Med.	Hard	Soft	Med.	Hard
Average number of heats for life of side walls	33	25	24	24	26	18	..	35	..

Comparison Between Life of Side Walls Refractories§ and Method of Laying Up the Side Walls

Method of laying up	Dry	Daubed	Dipped
Average number of heats for life of side walls	21	24	24

Comparison Between Furnace Capacity and Life of Side Wall Refractories for Different Methods of Firing

(a) Hand Fired Furnaces

Furnace capacity in tons	Up to 10	10 to 15	15 to 20	20 to 30
Average number of heats for life of side walls	44	23	27	20

(b) Pulverized Coal Furnaces

Furnace capacity in tons	14 to 20	20 to 30	30 to 50
Average number of heats for life of side walls	35	21	17

(c) Oil Fired Furnaces

Furnace capacity in tons	10 to 15	20 to 25
Average number of heats for life of side walls	27	19

Comparison Between Life of Side Wall Refractories and Different Methods of Firing

Method of firing	Hand Fired	Pulverized Coal	Oil Fired
Average number of heats for life of side walls	26	24	22

Life of Side Wall Refractories Compared With Various Qualities of Burn and Methods of Firing

Method of firing	Hand Fired			Pulverized Coal			Oil Fired		
Quality of burn	Soft	Med.	Hard	Soft	Med.	Hard	Soft	Med.	Hard
Average number of heats for life of side walls	28	25	27	..	26	22	..	28	18

*It is apparent that high top blast pressures have little or no effect on the side walls.

†While there is some lack of uniformity in the above figures for the life of side wall refractories, in general they indicate the better results obtained from thicker walls. There is involved the question of whether a wall can be too thick so that heat cannot radiate readily, thereby allowing the brick to soften. This question cannot be settled without a great number of tests operating the same furnace under the same conditions, using the same refractory material by varying the wall thickness and noting the heats obtained before side wall failure.

‡It will thus be noted that erosion is a larger factor in the short life of side walls than slag action.

§Joints protected with fire clay give greater side wall life than walls laid up dry. Dipping is to be recommended.

It is very evident that hard burned brick are not as serviceable as soft or medium burned brick. Medium burn is recommended.

Tap-out Blocks

The tap-out blocks are essentially a part of the side wall construction. Most furnaces have two—one on each side, but a few use four, two on each side. Tap-out blocks are subjected to a great deal of hard usage and much is dependent upon their long life. They must last as long as the side wall; otherwise costly shut-downs for repairs are involved as well as lost tonnage.

A tap-out block has to stand up and hold its hole size under the tapping rod and in many instances must withstand sledging to open up the hole if slag has accumulated or the hole frozen up. The flow of iron through the block cuts the hole and, as the block grows old in service, the hole is considerably larger. If the hole cuts away too large, the stream of iron is hard to control, and the danger element to workmen's safety enters in.

From all the reports received, practically every foundry has its own special size and shape of tap-out block. Some are round and some are square on the outside. Quite a few blocks are 9 inches deep and have the small hole size ¾ inches in diameter. The shape of opening in the block to the hearth varies in practically every one.

On this one item of tap-out blocks alone, standardization as to shape and size can be applied that will benefit the refractory producer and the consumer in lower costs for both. It is true that a few foundries cut out tap-out blocks from fire brick, some others ram up blocks from fire clay and crushed brick, but this is expensive practice generally.

The committee recommends two standard tap-out blocks to supplant the great variety now being used. One block should have a ¾ inch diameter hole for foundries using hand ladles and another block with a 1 inch diameter hole for furnaces served with bull ladles. The outside dimensions of the block could be 7½ inches square by 9 inches long with suitable flare from the hole to the face to allow room for the tapping rod and for plugging up.

We know of one refractories concern which makes more than 60 shapes in tap-out blocks for the malleable industry and there are many more among the other producers.

The quality of the block should, of course, be of proper burn and refractoriness to insure the maximum life.

Furnace Bungs

Bungs are used to roof over the entire furnace from the front wall of the fire box or combustion chamber to the stack and are placed crosswise of the furnace. The bungs consist of an arched iron frame work into which a combination of straight and arched shaped brick are laid. The brick are held in place in the frame work by tightening up the clamps on the ends of the frame. The bungs are then set on top of the furnace fire box and side walls. Because the bungs are heavy they are handled in and out of place by means of cranes, hoists, etc.

Bung refractory material must be of first quality as they are subjected to extreme high temperatures.

The bungs in middle forward part of the furnace termed "the charging bungs" are removed after each heat in order that the charge of iron may be put in the furnace and then afterwards replaced. These charging bungs are subjected to severe usage in the operation of taking off and replacing, and their life is materially reduced. When charging bungs are removed from a hot furnace, the inner white hot face of the bung brick is cooled too rapidly, thereby setting up destructive spalling action.

Probably some practical expedient such as placing the hot bungs as they are removed from the furnace into a sand box would retard the rate of cooling sufficiently to minimize spalling and checking.

The clamps holding the bung brick in place should not be tightened up too much at the beginning, only enough to hold the brick and frame together. After the bungs go into service they constantly change shape and the clamps should be tightened a little periodically as the occasion demands. The reason for this continual change in shape is that the bricks soften a little under the high temperatures and the arch has a tendency to flatten out and this deformation at the joints of brick must be taken up.

Warped or crooked bung brick constitutes a rather common reason for trouble and shortened life in the brick. If the bricks are crooked or warped and the pressure is put on the clamp to tighten the brick in place, 25 to 40 per cent of the brick will crack and thus many more joints are formed in the face of the bung and spalling action is thereby increased. This, of course, is a problem for refractory manufacturers to overcome in perfecting their methods of manufacture.

The bung line taken through a vertical longitudinal plane varies with the ideas of those operating furnaces. Some furnaces are practically straight and horizontal on top; others with a little pitch to rear, while other furnaces vary from this to the decided camel back roof. The point to be brought out is that with the variation in the bung line the adjacent faces of the sides of bung are not always parallel to one another and, unless the cross joints are well daubed up, the flame works through the joints because the furnaces are under pressure all the time and cutting and erosion take place at these cracks in the joints.

Fire box bungs are not ordinarily removed unless for replacement; hence they are not as much abused as the charging bungs. The temperatures are not as high in the fire box either. The charging bungs and the bungs immediately to the rear of them get the highest temperatures.

Bungs toward the rear bridge walls and in the neck to the stack stand up for very long periods in some cases. Of course, these are not removed except for furnace repairs or replacements and temperatures are somewhat lower than the temperature prevailing at the middle of the furnace.

In hand fired furnaces it is necessary to supply secondary air for complete combustion and to force the hot gases down on to the metal on the hearth. This secondary air is supplied through a wind bung located about over the front bridge wall. A blast pipe is carried over the top of the bung and anywhere from four to eight branches ranging in size from 1¼ to 4 inch diameter are led into the tuyere openings in the wind bungs. These tuyere openings are usually placed at an angle to the vertical projecting towards the rear of the furnace. A few foundries have special wind bung brick made with the tuyere openings molded in them,

but most foundries prefer to cut these slots or openings into the regular bung brick that they use on the rest of the furnace. This latter method is somewhat costly. Fire brick are fragile and a good many brick are broken by trying to cut these slots in them.

The committee feels that a standard wind bung brick with tuyere openings molded in it should be used and all the other various special shapes discarded. Some further investigation by a field man will be necessary to determine whether one or two standard tuyere brick will suffice for the industry or not.

Table 4

LIFE OF FURNACE BUNGS WITH RELATION TO SPRING OF THE ARCH

(Table Based on Spring Per Foot of Furnace Width)

Arch Spring Up to 1.5 Inches Per Foot

Location of bungs....................	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	44	22	56

Arch Spring From 1.5 to 2 Inches

Location of bungs....................	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	34	19	40

Arch Spring From 2 to 2.5 Inches

Location of bungs....................	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	29	16	51

Arch Spring From 2.5 Inches and Up

Location of bungs....................	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	..	11	29

The spring of the arch of bungs vary considerably—dependent on what size of arch or bung is used and upon the design of the bung frame. Ordinarily, it would be expected that the flatter the arch, the shorter the life of the bung refractories—due to the greater pressure required on the clamps to hold the brick in place. A study of the information received indicates that, in general, bungs with the greater rise have the shorter life, as will be noted from Table 4.

A great many sizes and shapes in bung brick are to be found in use in the various foundries, although the No. 101-103 and 105 series of bung brick are becoming more generally used as time goes on. We also find quite a few No. 1 and 2 arch brick going into bung construction. The No. 101-103 and 105 series seem to fully meet the needs of the industry, but instead

of having two lengths of brick in this series, viz. 13 inches and 13½ inches, the standard length should be made 13½ inches, and the 13 inch length eliminated. The reason that the 13½ inch length is recommended for standard is that it works in exactly with the 4½ inch and 9 inch dimensions on the standard 9 inch straight brick. The 13 inch long bung fits in with no other brick dimensions.

Depending on the capacity of the furnace and the means at hand for removing and handling the charging bungs, the width of

Table 5

COMPARISON BETWEEN WIDTH OF CHARGING BUNG AND AVERAGE NUMBER OF HEATS OBTAINED

Width of bungs in inches.....	9	13 & 13½	18	26 & 27	30 to 33½	57 to 84
Average number of heats for life of bung..............	20	18	24	20	19	15

charging bungs vary from 9 inches to 84 inches. There seems to be an economical width for bungs, as will be noted from Table 5.

It will be noted from Table 5 that best results are obtained with 18 inch wide bungs. This width is obtained by using two rows of 9 inch brick.

Apparently, bungs only one brick wide make too many cross joints which are attacked by flame action between the joints, and also there are just that many more joints to be battered up when handling the narrow bungs on and off the furnace. On bungs more than two brick wide, structural problems enter in, as the bung frame has to be very heavy to be able to safely lift on and off the wide heavy bungs. Also, it is possible for one brick to fail in a very wide bung and let the whole bung drop into the furnace, or at least put it out of service for a complete overhauling.

Bungs only two brick wide are more easily handled than the wider ones, due to the less weight involved and they contain just half the number of joints that single row bungs have for a given length of space on the furnace. Probably the reason that the 26 inch and 27 inch wide bungs do not average up as well as the 18 inch is due primarily to the fact that a 27 inch bung is 50 per cent heavier than an 18 inch bung, and not enough attention has been given the proper design of the bung frame.

Handling, abrasion, erosion and spalling are the biggest factors in the destruction of bungs. With erosion may be included brick of somewhat questionable refractory qualities. Spalling is not as great an element as first supposed. Table 6 indicates this clearly:

The method of laying up bung brick has a bearing on length of service obtainable as shown in Table 7.

Life of bungs vary according to the width of the furnace to some extent as brought out by data of Table 8.

Top blast or the secondary air has little effect on the life of bungs immediately in front of the wind bungs according to Table 9.

The life of fire box bungs in hand fired furnaces is somewhat dependent on grate blast pressures. The lower the pressure, the longer the life, as borne out by Table 10.

Hand fired furnace bungs have longer life than do either the pulverized coal or oil fired furnaces, according to the data of Table 11.

A comparison of various methods of firing for different furnace capacities is interesting as seen in Table 12.

The service obtained from different qualities of burn of the bung brick is shown in Table 13.

Fire Brick Specifications and Standardization

A review of the above paragraphs on reverberatory furnace operating conditions will give sufficient data for determining proper specifications for fire brick. Briefly, the malleable industry is using first quality fire brick in all parts of the furnace construction with very few exceptions.

The committee wishes to point out that before adopting any final specifications on refractories that fine and course ground flint clay brick be thoroughly investigated. It is believed that the finer grinds give somewhat better results because there is less expansion and contraction in the fine grind brick.

Many fire brick that otherwise would give good service fail in operation because the brick are not uniform in size or straight.

Table 6

COMPARISON OF LIFE OF CHARGING BUNGS BETWEEN QUALITY OF BURN AND CAUSES OF GREATEST TROUBLE

Causes of greatest trouble	Spalling			Handling & Abrasion			Erosion		
Quality of burn	Soft	Med.	Hard	Soft	Med.	Hard	Soft	Med.	Hard
Average number of heats for life of bungs	20	21	..	16	16	..	17	17	..

Table 7

COMPARISON BETWEEN METHOD OF LAYING UP BUNG BRICK WITH LIFE OF BUNGS OVER DIFFERENT PARTS OF THE FURNACE

Method of laying up	Dry			Daubed			Dipped		
Location of bungs	Fire Box	Charging	Rear	Fire Box	Charging	Rear	Fire Box	Charging	Rear
Average number of heats for life of bung	32	18	47	53	20	49	46	20	48

Table 8

LIFE OF FURNACE BUNGS FOR VARIOUS WIDTHS OF FURNACES

Furnaces Up to 6 Feet Wide

Location of bungs	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	35	14	54

Furnaces 6 Feet to 7 Feet 6 Inches Wide

Location of bungs	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	39	20	48

Furnaces 7 Feet 6 Inches Wide and Over

Location of bungs	Fire Box Bungs	Charging Bungs	Rear Bungs
Average number of heats for life of bung	44	20	40

Table 9

COMPARISON OF TOP BLAST PRESSURES IN INCHES OF WATER WITH LIFE OF BUNGS IN FRONT OF WIND BUNG

Top blast pressures in inches	Up to 5	5 to 10	10 to 20
Average number of heats for life of bungs	22	17	22

Table 10

COMPARISON OF GRATE BLAST PRESSURES IN INCHES OF WATER WITH LIFE OF FIRE BOX BUNGS

Grate blast pressures in inches	Up to 5	5 to 10	10 to 20
Average number of heats for life of bung	48	44	41

Table 11

COMPARISON BETWEEN LIFE OF BUNGS IN DIFFERENT PARTS OF THE FURNACE AND DIFFERENT METHODS OF FIRING

Method of firing	Hand Fired			Pulverized Coal			Oil Fired		
Location of bungs	Front		Rear	Front		Rear	Front		Rear
Average number of heats for life of bung	41	20	51	26	17	40	..	25	42

Table 12

COMPARISON BETWEEN FURNACE CAPACITY AND LIFE OF BUNGS IN DIFFERENT PARTS OF THE FURNACES FOR DIFFERENT METHODS OF FIRING

Hand Fired Furnaces

Furnace capacity in tons	Up to 10		10 to 15		15 to 20		20 to 30	
Location of bungs	Fire Box	Charging	Fire Box	Charging	Fire Box	Charging	Fire Box	Charging
Average number of heats for life of bung	28	11	43	18	45	23	40	18

Pulverized Coal Fired

Furnace capacity in tons	14 to 20		20 to 30		30 to 50	
Location of bungs	Front	Charging	Front	Charging	Front	Charging
Average number of heats for life of bung	22	14	21	18	..	21

Oil Fired

Furnace capacity in tons	20 to 25	
Location of bungs	Front	Rear
Average number of heats for life of bung	20	19

Table 13

COMPARISON BETWEEN LIFE OF BUNGS IN DIFFERENT PARTS OF THE FURNACE AND THE QUALITY OF BURN* OF THE BUNG REFRACTORIES FOR THE DIFFERENT METHODS OF FIRING

Hand Fired Furnaces

Quality of burn	Soft			Medium			Hard		
Location of bungs	Fire Box	Charging	Rear	Fire Box	Charging	Rear	Fire Box	Charging	Rear
Average number of heats for life of bung	32	17	39	42	19	52	None reported		

Pulverized Coal Fired

Quality of burn	Soft			Medium			Hard		
Location of bungs	Front	Charging	Rear	Front	Charging	Rear	Front	Charging	Rear
Average number of heats for life of bung	22	18	43	22	15	35	None reported		

Oil Fired

Quality of burn	Soft			Medium			Hard		
Location of bungs	Front	Charging	Rear	Front	Charging	Rear	Front	Charging	Rear
Average number of heats for life of bung	None reported			55	30	50	None reported		

*From all reports of service, medium burned bung brick give the best results, but it is desirable to have the burn on the soft side rather than the hard side.

Brick not uniform in size cause bad joints and crooked brick crack when in place, thus presenting another joint to spall.

Uniform quality of burn regardless of the degree of burn is absolutely necessary for long service.

After a review of the present day conditions with regard to reverberatory furnaces, the Committee suggests the shapes as listed in Table 14 as standard for the malleable industry. These

Table 14

STANDARD SHAPES RECOMMENDED BY THE SUB-COMMITTEE ON SURVEY OF CONDITIONS IN THE MALLEABLE INDUSTRY

Used for Side Walls, Bridge Walls, Etc.

Classification	Size in Inches
9-inch straight	9 x 4½x2½
9-inch large straight	9 x 6¾x2½ (for breaking joints)
9-inch soaps	9 x 2½x2¼
9-inch splits	9 x 4½x1¼
No. 1 Arch	9 x 4½x(2⅛–2⅛)
No. 2 Arch	9 x 4½x(2½–1¾)
No. 1 Wedge	9 x 4½x(2½x1⅞)
No. 2 Wedge	9 x 4½x(2½–1½)

Used for Bungs

Classification	Size in Inches
No. 101 Square bung	13½x 4½x3
No. 102* Angle bung	13½x12⅛x4½x3
No. 103 Arch bung	13½x 4½x(3–2⅝)
No. 104* Arch angle bung	13½x12⅛x4½x(3–2⅝)
No. 105 Arch bung	13½x 4½x(3–2⅞)

Used for Stacks

Circle Brick	Size in Inches
24-inch circle	9 x 4½x2½
36-inch circle	9 x 4½x2½
48-inch circle	9 x 4½x2½
60-inch circle	9 x 4½x2½
72-inch circle	9 x 4½x2½
84-inch circle	9 x 4½x2½
No. 1 Wedge	9 x 4½x(2½–1⅞)
No. 2 Wedge	9 x 4½x(2½–1½)

*Note that the recommended length of the No. 102 and No. 104 have been modified to conform with the 13½-inch series.

shapes recommended are now standards adopted by the Refractories Manufacturers' Association.

Most of the above recommended sizes do not carry any extras for size or shape other than the regular 9 inch equivalent. The No. 102 and No. 104 bung brick could probably be furnished on the same basis. The 9 inch large straight carries an 8 per

cent extra charge at present but quantity production might eliminate the extra.

In addition to these recommended standards, it was suggested in the body of the report that two standard tap-out blocks be used to supersede the great variety now used. Also that special tuyere bung brick be designed for general use. The two sizes of tile brick for bridging over skimming door openings, while adding variety to the list, are recommended because their use would cheapen the labor cost on furnace repairs and renewals.

Fire Clay

The fire clay ordinarily used in the industry today is a highly silicious clay and fuses at lower temperatures than the fire brick; therefore, the fire clay joints between the brick burn out and thus shorten the life of the brick. Better results would be obtained if fire clay with analysis more nearly approaching the fire brick analysis in silica and alumina were used. The joints thus made would stand up and more nearly equal the fire brick.

A number of foundries report the use of high temperature cements but, strange to say, indifferent results have been obtained in most cases. This probably is due to lack of knowledge in applying and using the high temperature cements. Very likely refractory life can be improved by the use of high grade cements but high temperature cement producers will have to educate the trade in their proper use.

Malleable Annealing Ovens

The white cast iron must be malleablized before it becomes a commercial product. The process consist of subjecting the castings to an annealing heat for a period varying from 120 to 200 hours, depending upon the melting process and the type of annealing equipment used. The maximum annealing temperature is about 1725 degrees Fahr., although this temperature varies with composition and sections of the castings to be annealed.

Annealing furnaces used in the malleable industry are generally described as the periodic pit type and end door types, and

the continuous kilns. The periodic furnaces are either hand coal fired, pulverized coal fired or oil fired. The very few continuous kilns are either oil fired or gas fired.

Up to a few years ago the periodic type of annealing furnace was the only method used in malleable annealing until the recent advent of the continuous type of annealing kiln.

Periodic furnaces after loading are heated up to temperature and are allowed to cool off to about 200 degrees Fahr. before unloading. Thus they are repeatedly being heated up and cooled off. Continuous kilns once put under fire are never or seldom shut down.

The refractory problems encountered in annealing furnaces and kilns are negligible because the temperatures are comparatively low when compared with the fusion point of even second quality refractories. However, the fire box or combustion chamber of periodic furnaces are faced with first quality refractories as these parts of the furnace come in direct contact with the fire, and temperatures will run up to around 2000 degrees Fahr. or higher.

Periodic furnaces vary considerably in size and capacity, ranging up to maximum lengths and widths of 30 and 20 feet, respectively. Due to these large dimensions, expansion and contraction are somewhat detrimental and it is necessary to tie the walls together with buck stays and tie rods.

The periodic pit type furnace consists of a box-like structure partially set into the ground and covered with removable bungs, the fuel being applied from one end.

The bungs present practically the only refractory problem due to the fact that the bungs must be handled on and off the furnace after each heat. The bungs are very heavy and failure results not from high temperatures but from the ordinary wear and tear from handling. Side walls are sometimes injured by improper lifting of the stacks of annealing pots into or out of the furnace.

The periodic door type annealing furnace is similar in shape to the pit type annealing furnace, except that the annealing furnace floor is on a level with the floor of the annealing room and the

furnace is loaded and unloaded through the removable front doors. The principal refractory problems in this type of oven are found in door failures due to handling the doors in and out of place after each heat. Some abrasion is found on the side walls of the furnace due to charging trucks running against them. The floors of the door type periodic furnaces get considerable wear from the charging trucks that must run over the floor of the furnace, hence failure of the floor tile is due to abrasion.

Ordinarily, a properly built periodic annealing furnace, reinforced for expansion and contraction, should last from 15 to 25 years. However, combustion chambers and fire boxes must be repaired occasionally as they are subjected to more intense heat.

The flues and stacks of periodic furnaces present no refractory difficulties.

The modern type of continuous annealing kiln being under fire all the time does not deteriorate from expansion and contraction, although these kilns are as long as 347 feet. The greater part of the kilns can be made of second quality refractories, although it is policy to play safe and build the soaking zone with first quality brick. Burner tile and combustion chambers are specially molded and of first quality refractories. With the proper application of fuel to the continuous kiln, the life of the refractories throughout the kiln should be indefinite.

In general, no special shapes or classifications of fire brick are necessary for periodic furnaces and it is the opinion of this committee that the American Refractories Association's classification should suffice. The continuous kilns require a number of special shapes but this is more or less necessary, due to design.

Core Ovens

The core ovens used in malleable foundries are the same and operate under the same conditions as do any other core ovens in other industries. Maximum temperatures of the ovens seldom exceed 400 degrees Fahr. Outside of minor repairs to the fire box or combustion chamber of the core ovens, there are no refractory problems to be met. For the fire box and combustion chambers first quality refractories should be used. The balance of the oven can be made from second quality refractories.

The American Refractories Association classifications on fire brick are suitable for all core oven work and it is the recommendation of this committee that these specifications be adhered to.

Ladle Drying Ovens

Ladle drying ovens present no refractories problems.

Respectfully submitted,

Subcommittee on Survey of Conditions in the Malleable Industry

Jas. R. Allan, *Chairman*
H. M. Thompson
J. H. Birdsong

Sept. 1, 1926.

Discussion

Chairman L. C. Hewitt: The Joint Committee organization has been brought about directly through the efforts of Mr. Ring and Mr. Cummings, who are chairman and secretary, respectively, of the A. F. A. Committee on Refractories. In the active organization of the committee the American Ceramic Society has been pleased to participate.

In selecting representation on the joint committee we have endeavored to enlist the cooperation of all major organizations that are interested in this work. Our aim in organization has therefore been to eliminate duplication of work on foundry refractories.

A further aim of the committee is to bring about a better understanding of the desired properties and the application of materials. This is broad in its scope, in that it brings in the matter of furnace design and simplification of both shapes and practice.

In respect to application, the first problem is to make a survey of the field and learn just what the existing conditions are. Into this survey would tie the matter of selection of refractory samples for test. This work will be undoubtedly done under the direction of a field man who will go over the reports that have been submitted, study the service conditions in detail and thus, with the knowledge before us of the desired properties of refractory materials and just what certain conditions are, we will be in a position to draft specifications.

The working plan of our committee has been to subdivide itself into sub-committees. On survey we have sub-committees relative to the malleable, cast iron, non-ferrous, and steel castings. Other committees are those on standardization and simplification, on tests, etc. These committees have all been active, as evidenced by the reports that have been distributed at this meeting relative to surveys on the non-ferrous, steel castings, and malleable industries. The committee on standardization and simplification has outlined its work. The interest in this has been manifest at the exhibit, which is in this building. The committee on specifications has prepared preliminary specifications relating to fire brick for malleable furnaces and annealing ovens.

We will call in turn for the reports by these committees, and they can tell us about the work in further detail. I would like to read the closing paragraph of the report on steel castings, for it seems as though it might outline the situation in general.

"In closing, it is the writer's opinion that the solution to the greatest problem of refractories users and manufacturers lies not alone in the development of new and better refractory ware but also in such improvement of the manner and methods by which these wares are used as will actually permit optimum performance. In other words, refractories fail much more often from abuse than they do through use; and while some work necessitates this abuse, the solutions of steel foundry refractory problems lies just as clearly in the manner in which refractories are used, as it does in the character of materials available and the designing of more modern furnaces, ovens, etc. (In other words, the scientific application of refractories is paramount to the development of new or better refractory articles.)"

CHAIRMAN L. C. HEWITT: Mr. Allan has given us a very interesting report. His committee is to be complimented on the work they have done. There are a number of points of interest that have been brought out and it is expected that they will arouse a great deal of discussion.

A. J. GRINDLE: I don't like to make any comments on this paper, but I cannot agree with Mr. Allan's survey. I would like to have you call on somebody using pulverized coal for comments on brick refractories. When the furnace is fired properly, with the proper mixture, not too much air, the saving in brick amounts to quite a bit.

J. R. ALLAN: With reference to Mr. Grindle's pulverized coal application, very likely with every installation he has put in he has been able to cut down the refractory cost because in adapting pulverized coal in the furnaces they have probably improved a number of other conditions.

W. R. BEAN: We have had experience during the past year with pulverized coal and have shown a reduced consumption of fire brick. When it comes to measuring the life of refractories in the reverberatory furnace,

it is extremely difficulty to draw accurate comparisons. The basis that we use is brick per ton of iron melted, and on that basis we are showing quite decided reductions from our hand-fired practice. In some cases as much as 50 per cent, in others not more than 15 or 20 per cent. But where the lower saving is shown, we had exceptionally good practice in hand firing. Mr. Allan's questionnaire was quite broad in the number of questions asked, and there were some of the questions that we couldn't answer. I think perhaps there would have been more returns if the questions had been fewer, because there were some things there that even the best plants would not have a record from which they could give data that would be valuable, there is not sufficient data available to answer the questions intelligently and definitely. The subject is one in which we are interested and have been for a number of years. We have almost come down to the recommended practice on the list of brick that is recommended in the survey.

One thing in connection with the bung brick, where we have to handle the bungs by hand, a 13½ inch brick makes a rather heavy bung, so that our use of that brick is now confined to the plants where we have crane equipment for handling them. I think that some will hesitate to adopt the 13½ inch brick as standard for that reason. There may still be a real need for a smaller brick, for the 9 inch bung brick for hand handling of the bungs.

There seems to be a difference in the life of bungs laid dry and with clay. We have just recently been doing some studying on that line and are not ready to say what the results will be, but I was glad to have what Mr. Allan reports on that for checking with what we are doing.

CHAIRMAN L. C. HEWITT: The questionnaire, of course, is something that it is difficult to obtain full and complete information on, and we realize that, but I think it has in this case given us some data on which we can work further and obtain more accurate information. You are very correct in regard to a measuring stick in computing your refractory costs, that is, basing them finally in terms of tons of metal produced. Of course, that is all any man is finally interested in.

C. E. BALES: I was much surprised to read what Mr. Allan and his committee had to say about powdered coal vs. hand fired and oil fired. It has been my experience that powdered coal fired furnaces gave better refractory life than those fired by hand or oil, due to the fact that in a pulverized coal fired furnace you have a more constant flow of fuel, with the proper amount of air, while in a hand fired furnace one minute you have an intensely reducing action, the next minute you may have an oxidizing condition. I think that is especially true on sidewall brick, where if you have an intensely oxidizing condition in your furnace, you get considerable oxidation of your iron and consequent erosion of the sidewall, or slag action. I have found in my visits that those who are using pulver-

ized coal correctly are getting better results than they did when they used hand fired methods. I know of only a few plants that are using oil and some of them are not getting very long refractory life, some are getting only one week, where with the same brick and the same sized furnaces using pulverized coal they are getting two weeks. So I believe that that statement might be subject to modification after Mr. Allan gets more returns on his questionnaires.

Another thing that I was very interested in is the comparison between firebox thickness and life of firebox sidewall refractories. Some foundry men might get themselves in trouble if they go to the other extreme of making their walls too thick. You will notice that around in the vicinity of 13½ inches he gets the best results. I think that the average thickness of sidewalls is about 13½ inches. That seems to give better results than a thinner wall or a thicker wall.

Another thing I was interested in is the relation between the blast pressure and service, as given in the report. This shows one thing here that I mentioned last year, and that is that the higher the blast pressure, the less the sidewall life, the less service you get from sidewall brick. I think this table bears that out to some extent.

There is one other thing that surprised me quite a bit and that is that in relation to bung brick they state that spalling is not as important a factor as we formerly thought. Now, I don't know whether it is true spalling or not, but the condition that we find in bungs is something where pieces of brick drop off. That is probably not pure, theoretical spalling, you might say, but it is a combination of other things which the furnace man usually terms spalling. So I believe yet that the term "spalling," as we now think of it, is descriptive of something that is highly important and highly destructive to bung brick.

There is one thing, too, that the report shows in regard to the spring of bung arches, seeming that the flatter the arch, the better the brick life. It may be that where you have too much spring in your arch, you have considerable pinching action. In some recent work that has been done at Mellon Institute they found out that pinching action is one of the contributing factors for the failure of bung brick.

Another contributing factor appears to be shrinkage of light burned bung brick, shrinkage and subsequent tearing.

I do think, Mr. Allan, you are to be congratulated on this paper, because you have a great many points there that are going to help the fire brick man as well as the malleable man.

J. R. ALLAN: We were very much surprised to find that the flatter the arch the longer the refractory life in bungs, and we concluded that Table 8 here more or less substantiates that. In other words, the wider the furnace, the longer the bung life.

With regard to wall thickness, a note is appended stating: "While there is some lack of uniformity in the above figures for the life of sidewall

refractories, in general they indicate the better results obtained from thicker walls. There is involved the question of whether a wall can be too thick so that heat cannot radiate readily, thereby allowing the brick to soften. This question cannot be settled without a great number of tests operating the same furnace under the same conditions, using the same refractory material by varying the wall thickness and noting the heats obtained before side wall failure." We are not in any position to recommend thicknesses, although in my own personal case I have gone to 22-inch walls.

F. A. Harvey: Mr. Chairman, I certainly think Mr. Allan is to be congratulated on his report, not only on the substance of the report, but on the number of answers that he got to the questionnaire. It is a very remarkable record to get nearly half of the people answering an elaborate questionnaire like this. He must have used some strong medicine to get these plants to go to the trouble that was necessary to bring that about. This report, of course, is going to be discussed and investigated, so that what individual points we bring out at this time will be just a guide for future work.

One point that occurs to me, I might indicate a lot of points that I have marked, but to take a point that has already been discussed here, in regard to Table 6. The people who report that spalling is their major trouble get the longest life from their bungs. That can be interpreted, as Mr. Allan says, that spalling is not as much of a factor as we had previously supposed, or it can be interpreted exactly in the opposite way. The other factors are handling and abrasion, and erosion. It can be interpreted to mean that the men who have eliminated the erosion, due, perhaps, to wrong direction of the flame or bad furnace design, and have eliminated their troubles from handling, are getting longer life, so that spalling becomes their major factor.

W. R. Bean: There is one further point that I might ask regarding the spalling, and that is, if a brick which spalls may not actually outlast in a bung a brick which is less refractory and goes to pieces or deteriorates by actually melting. It seems to me that that is the condition that exists there, and I don't object to a bung spalling, I think it is a pretty good sign, and that that bung will actually outlast many bungs which the furnace man would consider were better because he simply sees that the brick have spalled and doesn't actually know or have records showing how many heats they have lasted. A brick that spalls will many times outlast a brick that doesn't spall, not only in bungs but in sidewalls.

J. R. Allan: I think probably Mr. Bean has analyzed that point properly, in that it may be in the inferior quality of the refractory that so many people have their trouble rather than spalling. I have always felt that the various committees on test specifications laid too much stress

on spalling and not enough, probably, on the composition and manufacture of the brick.

Mr. Bales brought up a question a few minutes ago regarding the shorter life obtained from refractories in pulverized coal and oil fired furnaces than in hand fired furnaces. There is a pretty good reason for a little shorter life in pulverized coal and oil fired furnaces, because you are pushing your furnace to the utmost, getting as nearly perfect combustion as you can get, and you have higher melting temperatures, your heat is higher, and naturally your refractories are going to fail faster than in the hand fired furnace. You are saving fuel by doing it and there are other factors there that offset any loss in refractories.

W. R. Bean: I think there will be more difficulty in getting plants to go to a standard tap hole block than to any other thing on malleable refractories. We use a brick that is essentially 9 inches in size except that it is tapered off on one side and laid right in with the wall brick. We get a slot instead of a tap-hole, then ramming in the mud, we form the tap-hole in that. We can raise and lower our bottom at any time without interfering in any way with the sidewalls. We can change the capacity of the furnace 25 per cent and not bother our tap-hole brick. It seems to me that there is a definite advantage in having a slot rather than just a round hole, the elevation of which cannot be changed if the bottom happens to go down a little at that point or if it is desirable to change the capacity of the furnace between renewal of bottoms. This is one point where we can't quite see that it would be to our advantage to go along with the suggestions that have been made, and it is about the only one.

Chairman L. C. Hewitt: The way you have outlined your design, Mr. Bean, it would seem to have some very desirable features. Others here will no doubt be glad to take some notes on that.

J. R. Allan: There is just another case where a field man will function in determining those points.

I would also like to see a little discussion on the tile to be recommended for over the skimming hole rather than using arch brick. It is a considerable labor saver. We recommended two sizes of tile, 5 inches by 9 inches by 24 inches and 5 inches by 13½ inches by 24 inches to set over the skimming door and sampling hole rather than to make an arch of No. 1 arch brick, or maybe No. 2 arch brick. There is quite a saving in labor there and your refractory costs ought not to be any higher if they are adopted and accepted and everybody uses them. Quite a few foundries you will find are using large tile over those openings, with a resultant saving in labor.

W. R. Bean: That brings up a point which we have not actually tried, but I was talking to Mr. Allan and we will as soon as we get back home. There is just one question that comes to mind and that is whether

that tile will carry the load of the bungs as well over a fairly wide skimming door as the arch, whether a crack in that tile might not be harmful. That is the thing that I want to try out in actual practice and see. It seems to me to be a good plan. I have watched our men repairing and in some cases they have a form, in other cases they don't have. They do a lot of cutting of brick in those arches; it is a time-consuming operation, and even though the brick may absolutely cost more on the basis of the 9 inch equivalent, it looks to me as though it ought to be a good thing.

J. R. ALLAN: The average thickness of tile used at the present time is around 3 inches, and we thought that that was a little bit thin, although none have reported any excessive failures due to the thickness of tile used over those openings. We prefer to recommend the 5-inch thickness in order to equal two thicknesses of 9-inch brick.

W. R. BEAN: We put our top course of brick the other direction. Now, I don't know whether that is unusual practice or not, but we think that we get a better wall by laying the top course the 4½ inch way and the 5 inch thickness of brick isn't going to fit in with that practice. I don't know whether any other malleable foundries are putting the top course of brick on that way. There seems to be less breakage of that brick from the handling of bungs and throwing the charge on the brick, and there is not the same tendency of the brick to loosen as when it is laid flat. A 4½ inch thickness of brick would suit us better than the 5.

C. B. MANUS: We are using the tiles, both over the skim and float doors, and now we have gone to using them under the doors, finding that when you get support there from your brick along the side of the doors, there is no chance for iron to get under a split 4½ inch brick and raise it. It works very well, we haven't had any failures of the tile over or under the door. Ours is, I think, 25½ inches long.

Regarding the tap-hole block, I guess ours is one of the specials, too. I am not acquainted with the slot Mr. Bean uses, but ours is 9 by 9 on one face, tapering to 8½. We prefer a taper there, thinking that when it is necessary to chip out a hole, using the taper will help to keep the brick from loosening or moving in toward the inner wall of the furnace. There were a couple of cases where we ran out of our regular brick and we had to use the regular 9 inch for the tap-hole block, and it went all right for the two weeks the furnace ran, but we went back to our own tapered block again.

CHAIRMAN L. C. HEWITT: Are there any comments relative to the proposal to eliminate the 13 inch series in favor of the 13½?

W. R. BEAN: We are doing that at the present time. Why the 13 inch brick got into the standards I can't tell, but we have changed recently to 13½ for just the reason that Mr. Allan cites.

Preliminary Report of Subcommittee on Survey of the Steel Casting Industry

To the Joint Committee on Foundry Refractories:

Introduction

1. In the United States, steel castings are produced, commercially speaking, in plants using one or more of five major melting or refining processes; they are, in the approximate order of their importance, acid open-hearth, basic open-hearth, acid electric, basic electric, and cupola acid-lined converter processes. It is not considered desirable to go into the merits or faults of the various processes here, or even to indicate their usage. Let it suffice that these processes are in use; that naturally then, they have refractory problems to be solved, and it will be our purpose to portray the conditions met with under average operating conditions in plants using these various processes.

2. While it is true that the more important refractory problems are concerned with the melting unit employed, the use of manufactured refractory ware in the steel foundry is by no means limited to that unit.

3. There are to be also considered, the thermal requirements of the heat-treating ovens, the mold and core drying ovens, and plastic ladle lining materials. In these are constituted the major refractory problems of the steel foundry, and the requirements to be met are many and varied. As the melting unit has the most severe and intense of the heat conditions to be withstood, it is naturally of first importance. Considering the open-hearth process, whether acid or basic, furnace refractory problems are very similar. The acid furnace is so-called because the hearth is lined with a highly siliceous material (generally a nearly pure silica sand) which has an acidic reaction at elevated temperatures. The silica of the hearth attacks the basic oxides in the charge, forming a heavy viscous slag. The basic furnace hearth is lined with a strongly alkaline material (general magnesite or dolomite which has a basic reaction at high temperatures) and

with the basic metalloids of the charge (including lime) forms a highly basic slag, very thin and fluid, but of great volume.

4. With the exception of the chemical nature of the hearth, refractory problems are not greatly different in the two types of furnaces. In other words, the hearth of the two furnaces must meet the same requirements thermally and mechanically and be of an absolutely opposed chemical nature.

5. The use of tilting open-hearth furnaces is not common in steel foundries and our description will be confined to the stationary types.

The Open-Hearth Process

6. The open-hearth furnace, so named because the charge, or material to be melted is piled on the hearth, and exposed to the direct action of the flame is a reverberatory regenerative furnace. Fundamentally it consists of a steel platform on which is mounted the structural steel framework which supports the roof and reinforces the side walls, holds the door frames, etc. At the end of the furnace are the ports and uptakes, leading to the slag pockets. Behind the slag pockets are the regenerator or checker chambers. The flues, dampers, valves, and stack are the remainder of the various major parts of the furnace. The course of the draft through the furnace is through one of the regenerator chambers, thence through the furnace proper and the other regenerator chamber to the stack. The intense heat of the fuel combustion that is unabsorbed by the charge and furnace proper, is largely absorbed by the checker work or loosely laid brick in the second regenerator chamber. Periodically the direction of the draft and flame is reversed, so that the incoming air is heated to a high temperature by contact with the highly heated checker brick, and the first regenerator is accordingly reheated. By proper manipulation it is possible to keep the incoming draft at a temperature never less than 750 degrees Cent. which makes possible the high operating furnace temperature of approximately 1700 degrees Cent.

7. In considering the refractory requirements of the furnace, we will consider the materials now commonly used, and try to point out their weaknesses or causes contributing to their failure.

Considering the furnace components in the order of their relative importance and effect on the ultimate furnace life the following is offered.

Roof: 8. In both acid and basic furnaces, the roof most frequently determines the furnace life. If the roof be of the "Orth" type, repair and patching is facilitated, the danger of losing the roof is obviated, and other things being equal, the life is therefore increased. First quality silica brick is used throughout the roof. Under proper manipulation failure is due largely to erosion by oxide and sand particles carried by the draft and flame, striking the roof, which is at a temperature very near its softening point. If it is built of a high-grade silica brick, and the furnace is properly operated, the roof will not "drip" or melt away, though it will glaze over. At certain periods in the melting cycle, as toward the end of a heat, it may soften in some areas. According to the best available statistics, open-hearth roof temperatures at this particular point in the cycle may run to 1750 degress Cent. (3180 degrees Fahr.) which is very near the softening point of the best available silica brick. Particularly in gas-fired basic furnaces, the basic oxides carried by the draft and flame have a strong fluxing action on the roof, as can be noticed by examining brick from such a roof after it is taken out of service. This is also true but to a lesser extent in acid furnaces, and probably accounts to a great extent for the much longer life of an acid furnace roof.

9. The roof of a basic furnace will rarely last over 400 heats, and 450 is about a record. Acid furnaces can generally be depended upon to last for 1000 heats—average perhaps a trifle higher and under the best operating conditions 1500 heats would break no records.

10. Inasmuch as the furnace roofs are always carried or supported by the "skew" backs in the "roof channels," the static load on the brick is not great, being but the "arch stress"—and failure due to deformation under load is almost unknown. If the furnace, when put into service, is heated gradually, and the expansion of the roof brick permitted by proper and timely adjustment of the tie rods—spalling does not occur to an appreciable extent. After the furnace is working, spalling is almost

unknown except in case of too rapid cooling when shutting down, during charging, reheating too rapidly, etc.

11. The roof brick then should withstand a temperature of 1750 degrees Cent. without softening, and should be resistant to erosion, spalling, chemical reactions, according to the process to be used, and mechanically strong.

Front Wall: 12. The front wall (charging door side) is generally composed of silica brick above the junction with the hearth in basic furnaces; below that point a magnesite brick is customarily used. It is common practice to have one or two layers of a neutral brick such as chrome, to separate the silica and magnesite brick, but some melters claim that is unnecessary. Others use a layer of pulverized chrome ore on top of the magnesite brick and place the silica brick on this loose material.

13. The most severe action on the front wall is the cutting of the walls by the flame and draft, and is most severe toward the ends of the furnace. Around the doors, due to the infiltration of cold air, and the water-cooled door frames, the temperature probably does not exceed 1650 degrees Cent. Under good operating condition in acid furnaces the jambs and breasts of the furnace are built up (patched) at least once a week, and consequently the bricks are protected to a great degree. The door arches, and the roof along the front of the furnace are also protected considerably, with the result that failure or wearing away of the front wall is rarely a troublesome matter. In basic practice the jambs cannot be built up as high as in acid practice and the fluxing of the silica brick, and erosion by the particles in the draft, tend to reduce its life. The load on the front wall brick is merely that of the wall itself, as the roof is carried by the "roof channels" which are independent of the side walls. The brick in the front wall is subjected to great thermal shock during charging, tapping, or patching as the doors are then open and admit considerable quantities of cold air to the furnace. Mechanical abuse during the charging of the furnace is also an important factor of front wall life.

14. With a fresh charge heaped high in the furnace the flame is deflected around and over the pile, and the erosive action of the flame on the front wall and roof is quite severe. This

severity is counteracted to some extent by the lower temperature of these areas due to cooling while charging and patching the furnace, but is excessive none the less.

15. In basic furnaces, if the magnesite brick are used higher upon the walls than the hearth line, patching is possible but the sudden cooling during charging and patching aggravates their inherent tendency to spall.

16. Summarily then, the front wall is subjected to high temperatures 1650 degrees Cent. excessive erosion, mechanical shock, and sudden temperature changes.

Back Wall (Tap Hole Side): 17. The back wall has the same erosive tendencies to withstand and does not have the cool air infiltration to lower its temperature as does the front wall. Consequently the cutting action of the flame is more severe, and the life proportionately less. The hearth is generally built up high on the back side to protect the back wall as much as possible. Mechanical shock is not an important consideration in its life, except that improperly charging large pieces of scrap may cause trouble.

18. The back wall then has a temperature close to the maximum (1700 degrees Cent.)—has the very severe abrasive action of the flame and draft to withstand at this high temperature, and cannot be easily repaired by patching. If the back wall burns through, or softens and is cut away, it must be replaced at considerable expense, and may involve a complete, though temporary, shut down.

Bulkheads: 19. The bulkheads comprise the region in the furnace leading from the hearth to the ports. Ordinarily this region would be a very large mass of brick work but in most furnaces the floor is raised at this point, to save brick, and allow a circulation of air under the raised part of the floor or shell—which part is known as the chill plate, and tends to lower the temperature of the brick in this area. This consequently decreases the susceptibility to erosion by the draft, slag attack, and cutting, by direct flame impingement on this part of the furnace which keeps the surface here at a high temperature. If the furnace is designed with repairs in mind, and the side wall is "paneled" at this point, the bulkheads may be built up and

protected as occasion demands, with the granular material used in building up the hearth. Mechanical shock is not experienced in this part of the hearth except through faulty charging, but thermal shock is an important factor, due to the periodic reversal of the flame and draft.

Ports, Uptakes, End Walls: 20. These parts of the furnace are grouped together as they have almost identical service conditions to meet. The gas and air incoming, and especially the draft and products of combustion outgoing are traveling at a high velocity, carrying considerable quantities of oxide particles, and consequently fluxing and eroding the highly heated silica brick that forms these areas. In basic furnaces this condition is emphasized to an extreme point, and yet silica brick are generally used, as manganese brick spall too readily. Direct impingement of the flame on the ports, end walls, and in the uptakes, considerably shortens the life of these areas, as the temperature (up to 1750 degrees Cent.) induced renders the brick softer, weaker physically, and more active chemically. Mechanical shock is not a factor here—but the thermal shock due to reversing has a very severe effect.

Hearth: 21. The hearth of the furnace is built up of fine granular materials (sand for acid, and magnesite or dolomite for basic furnaces) fused into place a layer at a time. Inasmuch as the cold charge is dropped directly on the hearth, the bottom must be strong and dense, and able to withstand extreme mechanical shock. Also, it must be hard, that it may resist abrasion by the pieces of the charge that strike it. This means that the material used must be such that it will fuse or sinter into place readily, and yet will form a hard dense mass. It must sinter comparatively easily, and yet must not be soft, so as to be easily corrodible by oxides either originally in the charge or formed during the melting period. As the hearth can be patched after each heat and the "slag-attacked" areas repaired, chemical action or fluxing is not a troublesome problem with a good bottom. If the hearth is properly sintered into place when originally built, the material used is of the best available quality, the bad spots are properly patched after each heat, the bottom is "dried out" and the following heats properly handled; in other words, when

good materials and good furnace practice is used, trouble with the bottom is not common.

Slag Pockets: 22. It is rare that the refractory qualities of the brick used in building the slag pockets cause serious trouble. Conditions are bad, indeed, but if the slag pockets are designed large enough so that it will not be necessary to open them, or clean them out during the life of the furnace, a first quality silica brick will give very fair satisfaction. The brick in this location are subjected to sudden and frequent changes of temperature at reversing times. The outgoing gases in the slag pocket range from 1300 to 1600 degrees Cent. (higher in gas than in oil fuel furnaces) and the incoming gases may be from 800 to 1100 degrees Cent.—a sudden change, loss, or gain of approximately 500 degrees Cent. in fifteen or twenty minutes.

23. A large part of the material picked up by the draft in the furnace is deposited in the slag pocket, and the brick have to stand the corrosive influence of these oxides. However, as mentioned before, if the slag pockets are large enough (in acid practice) or can be easily cleaned out (in basic practice) silica brick answers very well and causes but little trouble.

Regenerator Chambers: 24. It is customary to use a first quality clay tile for the flues at the bottom of the "checker work," in the regenerator chamber. Temperatures there rarely go above 750 to 760 degrees Cent. For the checker work proper, practices vary. Some users recommend clay brick for all but a few courses on top at the front (slag pockets) end of the chamber (using silica there)—while others recommend the use of silica brick throughout. Temperatures vary from about 1000 to 700 degrees Cent. at the front and rear ends of the checker work, and from 1000 to 800 degrees Cent. at the front end at opposite times in the cycle. While this sudden gain or loss of temperature may constitute a severe thermal shock, silica brick seem to stand up very well, where they are used.

25. The problem of a checker brick is to pick up and give up heat easily, to remain unglazed, to be dense so as not to collect and hold the "flue dust" (slag, oxide particles, etc.) and hence impair their usefulness, and they should be cheap. The slag and other particles that settle on these highly heated checker

brick cannot be readily cleaned off—so that the brick can seldom be used again.

26. To sum up, the life of the checker brick is concerned more with the design of the regenerator chamber itself, than with the refractory qualities of the brick. If the brick be of an high order, the arrangement of the brick that keeps the interstical space open as long as possible, i. e. unclogged by slag and flux particles—will permit the longest life of the checker works.

Flues and Stack: 27. The flues and stack are generally lined with a second quality clay brick. Temperatures run about constant at 550 to 650 degrees Cent. and hence the service demanded of these brick is not severe. The oxide particles, constituting the "flue dust" are at such a low temperature, and reduced velocity, in these regions, that erosion and fluxing do not cause trouble.

The Electric Furnace Process

28. In the steel casting industry, the electric furnaces used are of comparatively small sizes, up to three tons capacity—generally of the three-electrode type, and perhaps, the predominant number are acid lined. The furnaces, mechanically compared to open-hearth furnaces, are extremely simple. While their refractory problems are, therefore, correspondingly few in number, the rapidity of operation coupled with the intense heat involved in the process, and the resulting chemical activity of the refractories, means that these problems are considerably more difficult of solution than are open-hearth refractory problems.

29. The ordinary steel foundry electric furnace consists of a plate steel bowl, with a door on one side and a spout on the other, covered by a roof through which the electrodes project into the furnace. The refractory problems, then, are practically contained in these two major parts, the bottom (including the side walls) and the roof.

30. Contrary to open-hearth experience, the hearth generally needs repair or replacement before the roof does, and brief consideration of the service demanded of it will show why.

The Hearth: 31. In both acid and basic electric furnace practice, in some plants it is customary to lay one layer of fire

clay or silica brick next to the shell as the first step in building the hearth. In basic practice magnesite brick are frequently laid on these, headers exposed—to form the main mass of the bottom and side walls, and the interstices are then filled with the semi-plastic or granular material used to complete the hearth proper. In adding this granular material, some users recommend adding it in comparatively thin layers, and fusing each in place before succeeding layers are added. Others recommend making a semi-plastic mixture by using a suitable bonding medium, compactly ramming the whole mass at one operation by means of a special form to maintain the desired internal contour, and fusing the entire mass at one time. In a great many cases where the rammed-in lining is in use, no brick is used next to the shell, the plastic mass forming both bottom and side walls.

32. It is considered good practice to have the door jambs and the door arches of brick—generally silica brick—in both acid and basic lined furnaces. In basic furnaces, the practice is similar to that followed in open-hearth work, namely to run the basic material either brick, or bonded dolomite or magnesite, well up to the sides, separate the silica jambs and arches by a layer of neutral material, and use silica arches, etc.

33. Actually then, the refractory problem in an electric furnace (acid lined) is quite simple. Relatively pure silica sand, quartzite and ganister are commercially available at fair prices, and can be properly and easily bonded to make a firm rammed-in lining. The patching of the hearth after each heat is also comparatively simple on account of the small size of the furnace. Due to the fact that the charge is melted in a neutral, or at least non-oxidizing atmosphere, no excessive amounts of basic oxides are formed during the melting period, and the consequent scorification of the hearth is close to the minimum. The result of this is that a heavy, viscous, siliceous slag is carried at all times, and the extreme heat of the electric arc (in excess of 3400 degrees Cent.) is reflected strongly against the roof and side walls. Splashing, caused by the arc penetrating the bubbling slag, causes particles of slag to fly against the side walls and roof and aggravate the tendency of these parts to flux away.

34. The requirements of the electric furnace refractories then are: resistance to extreme high temperatures, and the ability

to withstand the sudden cooling and reheating which occurs when the furnace is charged without dimensional changes. Resistance to chemical attack by the slags carried is of course of considerable importance (more in basic than in acid practice) but is not of the extreme importance here, than it is in open-hearth practice on account of the comparatively quiet non-oxidizing furnace atmosphere.

35. There is some controversy at present concerning the heat conducting properties of electric furnace refractories. Some users recommend a heavy insulating lining to retain as much heat within the furnace as possible, while others recommend that heat conduction be favored, claiming that high conductivity will increase refractory life sufficiently to offset the power loss thus encountered. It is evident that if the refractories available could withstand the intense heat, and sudden temperature changes, the insulating lining would be the most economical.

The Roof: 36. The roof of an electric furnace is called upon to withstand all of the severe requirements of the side walls and many of them exaggerated to an extreme degree. In both acid and basic practice the roofs are composed of silica brick, standard or special shapes, and in many cases are extremely short lived. The temperature of the lower (inner) surface of a roof when a heat is melted is around 1750 degrees Cent. and the roof brick must withstand this temperature without undue softening. They must also carry their own static load combined with the "arch" or "dome" stresses. This means that high density and mechanical strength are necessary at high temperatures. A minimum coefficient of expansion is necessary, as electric furnace operation for foundry work is generally intermittent, "shut downs" at night and over Sunday being of common occurrence.

37. In basic furnaces, the lime fumes from the lime loaded slag, and fluorine fumes from the dissociation of fluorspar, cut the roof and upper walls (if of silica) in an intense manner, and contribute very considerably to the short life of these parts in basic furnaces.

38. Resistance to spalling is very necessary. Some furnaces are charged by removing the roof and dumping the cold charge on the hearth, and naturally the sudden cooling of the roof under

such conditions has a very severe effect. At best, the heaping of a charge of cold scrap high in the furnace, as is customary in "door charged" furnaces, cools the roof to an extreme extent. Remarks made in regard to heat conduction of the lining applies also to the roof with the added factor of electrical conductivity. This latter should be as low as possible, to avoid current leakage from electrodes to ground through the roof, with the resulting resistance heating of the roof brick. This is not only extravagant from the power consumption standpoint, but also decreases the life of the roof, through local overheating, to some extent at least.

The Cupola—Converter—Process

39. The cupola, producing iron in a molten state, is not of prime importance in this discussion. Its refractory requirements are well covered elsewhere. The converter, however, has problems unique to itself and to steel, and will be briefly considered. The use of the converter in steel foundries is not general. By far the majority of converters used to make steel for castings are found in what are normally gray iron or malleable iron foundries, and the converter is kept to make the occasional heat of steel that may be required. Its use, then, is at best intermittent, and the refractory life is consequently greatly affected by this spasmodic operation.

40. The converter consists essentially of a steel shell, (roughly cylindrical in shape) which is lined with a refractory material (acid or basic). The molten iron from the cupola or air furnace is poured into the converter and air is forced through the metal. The oxidation of the metalloids in the iron by the oxygen of the air, being exorthermic, raises the temperature of the metal, and an extremely high degree of heat (1650 degrees Cent.) and higher may be reached by forcing or extending the blow.

41. The converter lining is of course subject to attack by the oxides of the metalloids, and any slag or slag forming ingredients that might have been in the iron as it came from the cupola. Inasmuch as most converters used in steel foundries are acid lined, it is the iron, manganese, and phosphorus oxides that attack the siliceous lining. The lining for a converter is quite similar

in construction to the acid electric furnace lining, consisting of a monolithic, silica sand, or ganister lining, in some cases backed up by silica or fire clay brick, and in others, the lining is rammed directly against the shell.

42. The granular material used (sand, ganister, etc.) is generally bonded with fire clay and rammed securely into place. Between heats, the lining can be patched with a more plastic mixture, or "daubed," as necessary.

43. The tuyere blocks, or air inlets to the bath are generally composed of silica or magnesite brick especially shaped. It is of course at this point that the greatest erosion and fluxing takes place. The tuyeres are subjected to intense heat, and are naturally then chemically active. The oxides formed at the mouth of the tuyeres correspondingly attack them first, and failure on account of fluxing away is the chief cause of tuyere failure. Converters are generally so designed that new tuyere blocks can be quickly and easily installed. The bottoms are generally replaceable easily, as the wear there is also excessive.

44. Due to the fact that converters are operated intermittently and the temperature changes are correspondingly great and rapid, any refractory that spalls readily is unsatisfactory. In acid practice using a clay-bonded granular material, spalling is not a serious trouble. The main requirements of the converter lining are that it will withstand a temperature of 1700 degrees Cent. erosion by the blast and flame, and be as resistant to slag action (chemical fluxing) as is possible.

Ladles

45. Irrespective of the type of melting unit employed, ladle problems are very similar in all steel foundries. Converter and electric furnace steels are generally tapped at temperatures from 50 to 100 degrees Cent. higher than open-hearth steels, but on the other hand, in much smaller lots, so that refractory problems are similar. Generally speaking, the open-hearth shops (both acid and basic) use ladles of the "bottom-pour" type, while the converter and electric furnace plants use either a regular open ladle or a variation called a teapot spout ladle, pouring "over the lip" into intermediate and shank ladles, and from these latter into the molds.

46. Considering the bottom-pour ladle, there are three distinct refractory problems; the ladle lining, the nozzle, and the stopper. Ladle practice for linings varies considerably in different shops, but may be said to be of two general classes. The first may be said to be the practice that uses a bare brick lining, i. e., not covered with any plastic or semi-plastic material, other than a thin wash. The second class uses a brick lining protected by a layer from ½ to 2 inches thick of a plastic clay, sand mixture called "mud."

47. The brick used for the ladle linings in either case is generally a first-class clay product, and generally the mechanical abuse the brick receives, while in service, determines its life. When a ladle is newly lined, the bricks are set with a fire clay or high temperature cement mortar and then given either a thin wash of this cement or mortar, or heavily mudded. Then a wood-fire is built in the ladle to dry it out, after which it is heated, generally with a soft oil flame, for several hours, until the lining is incandescent and thoroughly dry, when it is ready for use.

48. Between the time the drying flame is cut off and the ladle is filled with the molten metal from five to ten minutes may elapse and of course the ladle cools rapidly. Then there is the sudden shock as the metal strikes the ladle, and an immediate change in temperature from 700 or 800 degrees Cent. to 1500 to 1600 degrees Cent. The slag penetrates the lining to a certain extent, and as the ladle is emptied, this penetration proceeds downward, acting at the junction line of metal and slag. When the heat is all poured, the ladle is cooled and the slag is chipped off the sides to maintain the ladle capacity. During this cooling whether with air or water the lining of course shrinks, and if the cooling is quite rapid, may fall out in certain areas. Then, too, the chipping of the slag is accomplished with bars and sledges, and the original ladle lining frequently suffers from this treatment.

49. Considering the plastic or mud lining, the refractory requirements are as follows; the material should be quite "sticky" when wet, should work easily, dry out with a minimum of cracking, be hard to resist the erosive action of the metal as the ladle is filled, should be impervious to slag, and above all should not

flux or fuse at the temperature of the metal. With the "bare brick" lining, the brick must not expand or contract greatly, as the ladle is heated and cooled. They must be highly refractory, resistant to erosion, spalling, and impervious to slag, and must be set into place with a very good high temperature cement, or a very good fire clay mortar.

Nozzles: 50. The nozzles are generally made of very refractory clay, and they must be able to resist cutting by the metal when the stopper is raised, be sufficiently refractory to resist fluxing, and must not soften or disrupt under the pressure of the stopper when the stream of metal is cut off.

Stopper Heads: 51. The stopper heads are generally composed of a clay and graphite mixture, and must not soften under the heat influence of the metal, or disrupt under the pounding sometimes given it to seat it firmly in the nozzle. If either the stopper head or nozzle softens when the stopper is left in its seat for a very short time, it is apt to stick there, and be pulled from the stopper rod, and consequently, control of the metal will be lost, and naturally a large part of the heat will be pigged, spilled, or otherwise wasted.

Stopper Rod Sleeves: 52. Stopper rod sleeves are generally made of a highly refractory clay, and must be capable of withstanding the metal temperature, and the sudden heat when the ladle is filled, without cracking, spalling, or fluxing. Slag penetration is an unimportant point as stopper rods are never used more than one heat.

Lip Pour Ladles: 53. The "open" ladles, lip pour, or teapot spout ladles used by the steel foundries with the smaller melting units have the same lining problems as the larger bottom-pour ladles, with this difference; the electric furnace and converter plants generally handle steel up to 100 degrees Cent. hotter than the open-hearth plants, and their ladle linings must naturally be more refractory if possible. In addition to the two methods outlined for the bottom-pour ladles, these smaller ladles are frequently lined by ramming a semi-plastic material (generally sand or crushed ganister and clay) around a form set in the ladle.

After the lining is rammed, the form withdrawn, and the contour of the lining is perfected, a wash of clay, molasses, etc., is used over the entire exposed surface, to harden, close the pores, and increase the strength of the surface of the lining. This same practice is commonly used for the shank and intermediate ladles also.

Teapot Spout Ladles: 54. In the case of the teapot spout ladles, the spout is either rammed or formed of specially shaped blocks. These latter may be of the same material as the lining proper, or may be a commercial clay or silica product. In any event the refractory requirements are primarily the ability to withstand temperatures up to 1700 degrees Cent. and at that temperature be resistant to erosion, fluxing or slag attack. Inasmuch as these spouts should last for the life of the ladle lining, they must also be resistant to spalling, which tendency is aggravated by the sudden heating when the ladle is filled, and the cooling between heats when the ladle is cleaned out.

Mold and Core Drying Ovens

55. The construction of the drying ovens, as influenced by the type of fuel to be employed, absolutely determines the refractory requirements of the materials used. Perhaps the simplest type is that employing gas as a fuel, with low pressure, or atmospheric blast burners running the length of the oven, either in a pit or along the side walls near the floor. With this type of oven there are no combustion chamber problems, and except in the vicinity of the burners, no excessive temperatures. Oven temperatures rarely exceed 400 to 450 degrees Cent. and almost any second or third grade clay brick will answer satisfactorily. The problems connected with drying ovens are primarily those of heat insulation, i. e., the heat generated by the burners is to be retained within the furnace chamber to the greatest possible extent, and radiation losses of all kinds are to be held to the minimum. With electricity as the heat energy source, the insulating characteristics of the chamber become more important because the temperature differential between the heating elements and the oven atmosphere is not as great as it is in the case of any flame-heated furnace. For this reason heat

absorption and later radiation by the walls and roof is not desirable.

56. In the case of fuel (coal or coke) or oil-fired furnaces (or gas if used in a pressure burner) the excessive flame temperatures in the fire box, or combustion chamber naturally require more refractory materials to be used in those locations than in the former cases. For these areas, a first-quality fire brick is used, as the high temperatures of operation coupled to the intermittent cycle necessarily followed, would cause excessive spalling of silica or similar materials if used. Hence in the combustion chambers there is the intense heat of combustion to be withstood, the tendency to spall to be overcome, and the problems of heat insulation and radiation are much less important than the others. Resistance to cutting or erosion by the flame (and slag in the case of coal fired installations) is also important.

Heat-Treating or Annealing Furnaces

57. The refractory problems of heat-treating or annealing furnaces are very similar to those of drying ovens, differing only in degree. Whereas in drying ovens the maximum oven temperature is around 450 degrees Cent., in heat-treating furnaces it may run to 950 or even 1000 degrees Cent. This naturally means that a higher grade of material must be used for the latter class of construction.

58. The fuel used, and consequently the furnace design, has a great effect on refractory life, in the same manner as in the case of drying ovens. The various types of annealers in use today all have individual specific service problems and it would be useless to detail them all here. There are, for instance, car annealers and pit annealers, intermittently and continuously operated, overfired, underfired, directfired, recirculating, and regenerative, using coal, oil, gas, or electricity as a heat energy source, all with their own individual problems to be solved.

59. In general, the refractory problems of the fuel-fired furnaces are the most severe. The real refractory problem is in the combustion chamber, and the areas upon which the flame impinges directly. Actual oven temperatures should never get to the temperature at which first-grade fire brick will soften or

run, except in these localized areas. The extent and number of these areas depend of course upon the size and design of the furnace, and that latter is dependent upon the heat energy source.

60. In general, electric heat-treating ovens have the simplest refractory problems. The oven temperatures are quite uniform, and the heat application is more or less general throughout the chamber, and perhaps of prime importance, the temperature gradient as the furnace is heated is quite low. The oven proper never has excessive temperatures to withstand under normal operating conditions and, due to the character of the heating media, the walls and roof are made as nearly heat insulating as possible.

61. In coal-fired installations, besides the fire box problem which is rather generally understood, there is the "port" or inlet to the oven proper for the flames, which have a decidedly erosive action. The intense heat generated also may cause running of the brick, and the intermittent operation aggravates any tendency of the brick to spall. For this reason a first-quality clay fire brick is generally used thoroughout a fuel-fired oven, and in these regions of excessive overheating and rapid cooling have all too short a life.

62. In the oil and gas installations, particularly of the direct-fired type where the flame impinges on, or is directly reflected by the roof, it is natural that the roof brick suffer severely. Not only are they subjected to the intense heat of the oil or gas flames, but also they have the roof arch stresses, and the sudden heating and cooling with its consequential expansion and contraction to withstand. In the old-fashioned pit annealer, where the roof is in the form or arch "bungs" and is removed to load and unload the pit, the temperature extremes to which these bungs are subjected shortens their life very materially.

63. On account of this and other evident disadvantages of these pits, they are rapidly disappearing, and are being replaced by more modern car annealers. It is evident that even though a car annealer be allowed to cool rapidly with the doors open, and the cars out, it would not cool anywhere nearly as fast as a pit annealer with the roof removed.

64. Annealer designing has advanced now to where, by means of recirculation, regeneration, and proper burner arrangement and adjustment, an oil-fired car annealer has been built that permits not only complete seal of the oven at the doors and cars bottoms, but also has its refractory brick work surmounted by a layer of insulating brick to increase the thermal efficiency of the installation. It does not only that, but incidentally, has no ruinous effect upon the refractory brick work, as would be the case in the old style oil or gas-fired furnaces that had to permit great heat radiation from the roof and walls of the furnaces to enable the brick to keep from running.

65. In closing, it is the writer's opinion that the solution to the greatest problem of refractories users and manufacturers lies not alone in the development of new and better refractory wares, but also in such improvement of the manner and methods by which these wares are used as will actually permit optimum performance. In other words, refractories fail much more often from abuse than they do through use; and while some work necessitates this abuse, the solution of steel foundry refractory problems lies just as clearly in the manner in which refractories are used, as it does in the character of materials available and the designing of more modern furnaces, ovens, etc. (in other words the scientific application of refractories is paramount to the development of new or better refractory articles).

Respectfully submitted,

Sub-Sub Committee Survey of Refractory
Requirements of the Steel Casting Industry,
C. N. Ring, *Chairman*

Preliminary Report of Subcommittee on Survey of the Non-Ferrous Foundry Industry

Introduction

It is considered advisable to submit a preliminary report at this time, to be followed a little later by a somewhat more elaborate discussion of the information which has been collected by this Committee. It is the purpose of this report to indicate the most obviously important features of the very considerable amount of data which has been submitted by upwards of eighty brass foundries. A more intensive analysis of these data will doubtless provide material for additional conclusions of interest and importance, and, in some instances, may even slightly modify the general conclusions given in this report. Such an intensive analysis will be made and the conclusions embodied in a final report.

Manufacturing conditions in American brass foundries are exceedingly variable. The type of furnace used, the composition of the alloys melted, the physical nature of the charge, pouring temperatures, production schedules, the various items which go to make up operating practice: all of these factors vary widely from plant to plant and each plays its part in affecting the life and satisfactory use of refractories. Some of these items are under the control of the individual foundry, others are prescribed by the nature of the work done and cannot be varied for the sake of gaining better refractory results.

Brass casting shops in the United States, exclusive of brass rolling mills, can be divided roughly into four classes:

1. Foundries which normally operate their furnaces at full productive capacity on a small number of alloys, with little day to day variation in melting practice.

2. Foundries which normally operate their furnaces at full productive capacity but with alloys of widely varying composition, poured into a variety of castings under conditions which

differ greatly from day to day. The large jobbing foundry is an example of this type.

3. Foundries which commonly operate their furnaces at less than full productive capacity but do not deal with a large number of alloys or varied products.

4. Foundries which commonly operate their furnaces at less than full capacity and also deal with widely varying alloys and products. This is typical of the small jobbing foundry.

The individual items which affect refractory performance in the foundry may be listed as follows:

1. The type and size of furnace used and the fuel used with it.

2. The rate of production, that is, the average number of hours out of the twenty-four, during which the furnace is actually melting metal, and the degree to which the melting process is being forced.

3. The number and composition of the alloys melted.

4. The average temperature at which the metal leaves the furnace.

5. The presence of foreign non-metallic materials in the furnace whether due to dirty metallic materials in the charge or purposely introduced as fluxes or covering slags.

6. The degree to which the furnace is kept clean of slag and the methods used for removing it when present.

7. The nature of the refractory used for lining the furnace and the care taken in preparing the lining for service.

8. The frequency with which the lining is patched, the nature of the patching material used and the method of mixing and applying it.

A questionnaire embodying the above items was sent to 225 representative brass foundries. Eighty-three replies were received, a return of approximately 37 per cent. This proportion of replies is considerably higher than is usually the case with questionnaires and is considered very gratifying. The information received in these replies has been supplemented to some extent by verbal information received from other plants. While the foundries which have given us information probably comprise

less than 25 per cent of the total brass melting capacity of the country (exclusive of rolling mills) it is believed that the information received is fairly representative of general practice. Foundries of all four types mentioned above are well represented and an exceedingly wide variety of operating conditions is found in the replies.

Furnace Types and Fuels

In 1914 Gillett[1] listed 27 types of furnaces commercially used in melting brass. This did not include several types of electric furnaces, now used, which had not then been sufficiently perfected for practical use. For the purpose of this investigation a less minute subdivision may be employed and the furnace types now in use may conveniently be classified in eleven groups as follows:

A. Using coke or hard coal
    1. Crucible pit
B. Using soft coal
    2. Crucible pit
C. Using oil or gas
    3. Crucible pit
    4. Crucible tilting
    5. Open flame tilting
    6. Open flame rotating
    7. Reverberatory
D. Using electricity
    8. Indirect resistance
    9. Indirect arc, rocking or rotating
    10. Induction
    11. Direct arc.

In ordinary foundry practice, types 1, 3, 4, 5, 6 and 9 are in common use and will receive principal consideration in this report. Type 2 is of little present importance although in a modified form it may possibly be of future importance. Type 7 is of important use in smelting plants for melting down and refining low grade or badly contaminated materials. Type 8 is

[1]Gillett, H. W., U. S. Bureau of Mines Bulletin 73, Brass Furnace Practice in the United States, p. 17.

of declining importance if one is to judge by comparison of the number of furnaces of this type in present use with the number in use three or four years ago. Type 10 is very widely used in brass rolling mills but its present use in foundries is rather limited. However, its potential importance is considerable and, since its limitations are principally due to refractory problems, it deserves substantial recognition in this report. Type 11, while the favorite electric furnace for steel melting, is not suited for use with brass foundry alloys. It is believed that its employment for such purpose is confined to intermittent use in a single plant. Other furnace types have been suggested and may in the future become of importance, but the scope of this report is limited to a survey of present conditions and too wide a speculation as to the future would be out of place. Under this head may be included a number of electric furnace types, reverberatory crucible furnaces and furnaces using powdered coal.

Furnaces Using Solid Fuel

This classification includes groups A and B and is limited to crucible pit furnaces. Twenty-five plants reported the use of furnaces of this type, melting a daily total of 324,000 pounds. This represents a total of 30.1 per cent of the plants reporting but only 18.5 per cent of the total melted. Out of the 25, two plants use these furnaces intermittently only, while 11 others depend on other furnaces for at least a substantial proportion of their melt. Twelve plants, four of which melt 10,000 pounds of metal or more per day, depend upon this type of pit furnace exclusively. Of the 25 plants, 21 use coke as a fuel, three use hard coal and one uses soft coal.

The life of the pit linings varies from 100 heats to 1500 heats in different plants, averaging 670 heats. Compared with the data collected by Gillett (loc. cit. p.p. 46-47) the maximum life is about the same but the present average is about 90 heats higher than it was in 1914, assuming that the two collections of data offer a fair comparison. In each case about four heats per day from each pit represents average practice. The nature of the fuel does not seem to make as much difference as might be expected, although so few of our replies are based on the

use of hard coal that no real conclusion can be drawn. There are no data at all from the one soft coal installation.

The linings of pit fires are customarily built of cupola blocks, ordinary fire brick shapes, or various plastic mixtures rammed into place. The most rapid wear occurs in the ash zone and is due to the fusing of slag and clinkers to the lining. In cleaning the fires these adhering clinkers are usually chipped off with a bar and this process gradually destroys the lining. This is also the region of most intense heat.

After a survey of the data one is forced to the conclusion that the personal element is of predominating importance. Linings would stand up for a long time if they had nothing but fire to contend with, the handling of the bar in tending the fire and in cleaning the pits largely determines the durability of the lining. Variations in this respect are so great as to obscure the effect of other factors. It seems probable that a rammed lining of suitable material, skillfully installed, will outlast a brick lining. It follows also that the same material skillfully used as a patch in any lining will greatly prolong life. In both cases skill is necessary and a little sympathy on the part of the furnace tender is also essential. Average conditions should be greatly improved by the use of a slag resisting material more refractory than common fire brick.

Crucible Furnaces Using Oil or Gas

This classification includes types 3 and 4, Group C. Twenty-five plants reported the use of furnaces of this type, melting a daily total of 157,250 pounds. This represents a total of 30.1 per cent of the plants reporting but only 9 per cent of the total metal melted. In many instances the furnaces are used as spares or for special purposes only. Very few plants depend on this type of furnace for the bulk of their production. Of the twenty-five, eighteen plants use oil exclusively, four use oil or gas while three use gas exclusively.

The average life of the fire chamber linings in different plants varies from 100 to 2000 heats, averaging 775 for all plants combined. The destruction of the lining is due to the cutting action of the flame and to the decomposition of unburned oil

which finds its way into the cracks and pores of the refractory. The replies received by Gillett showed an average of 1020 heats per lining from this type of furnace.

The linings of these oil crucible furnaces are usually made from common fire brick or from a rammed furnace mixture, the latter being quite popular and usually containing considerable proportion of carborundum. It appears from the data that such a rammed lining outlasts a fire brick lining by about 50 per cent. A glazed surface on the lining before it is put in service is an advantage. Preheating and regular patching help to increase the life of the lining; neither is universally practiced.

Open Flame Furnaces

These use either oil or gas (usually oil) and include type 5 and 6 of Group C. Forty-one plants reported the use of furnaces of this type, melting a daily total of 682,300 pounds. This represents a total of 49.4 per cent of the plants reporting and 39 per cent of the total metal melted.

The life of these linings varies from 75 to 1900 heats in different plants, averaging 520 heats when the replies are combined into a composite figure. Destruction of the lining results from the following factors:

(a) Spalling.

(b) Cutting action of the flame.

(c) Fluxing action of floating slags.

(d) Fluxing action of particles of slag thrown against the refractory of the blast.

(e) Mechanical injury due to charging heavy pieces of metal.

(f) Chipping out adhering slag.

In cylindrical furnaces of this type pure brick linings are ordinarily used. In egg shaped furnaces rammed linings are common although furnaces lined with brick and partly with a rammed mixture are rather more usual. Other things being equal, the brick linings seem to stand up better than the rammed linings.

In cylindrical furnaces best results are obtained by running

the furnace at about half its rated capacity per heat and taking out a proportionally large number of heats per day. This actually results in the largest tonnage melted per lining. Charging more than the rated capacity of the furnace shortens the lining life materially. In the egg shaped furnace this factor seems to be of little importance.

Best results are obtained by preheating with wood or charcoal, then applying a slow oil fire for several hours. Glazing the surface of the lining before service is beneficial.

Periodical inspection and patching is much better than "patching as needed." The best combination seems to be daily hot patching plus weekly cold patching.

The composition of the metal does not seem to be of great importance, although very high lead undoubtedly has some detrimental effect.

The uses of fluxes is hard on the lining, lime and fluorspar being particularly bad. Really dirty metal, particularly if contaminated with oil or grease, is harmful to the refractory. Furnaces, if reasonably clean, have no detrimental effect.

The slag problem is not likely to be serious if the furnaces are run steadily at a high temperature. Small doses of a mild cleaner (probably with a fluorspar base) are effective under these conditions. More drastic measures, such as the use of salt, lime and fluorspar, or high heat in an empty furnace are destructive.

Indirect-Arc Electric Furnaces

This includes Type 9, Group D. Twenty-two plants reported the use of furnaces of this type, melting a daily total of 341,950 pounds. This represents a total of 26.5 per cent of the plants reporting and 19.5 per cent of the total metal melted.

The reported life varies from 400 to 4000 heat and averages 1350. Destruction of the lining results from the following factors:

(a) Spalling
(b) Fluxing action of floating slags
(c) Mechanical injury in charging
(d) Removing slag
(e) Penetration of metallic vapors and oil.

In nearly all cases a high grade disapore fire brick is used. Periodical patching is almost universal although details of practice vary widely. Daily hot patching and weekly cold patching gives best results. Preheating is universal although there is considerable variation in the nature and duration of the preheat. Spalling is the most serious single factor in shortening lining life, although penetration of the brick by metallic vapor or oil from the charge is also very destructive in certain plants.

Electric Induction Furnace

This classification includes Type 10 of Group D. Six plants reported the use of furnaces of this type, melting a daily total of 78,000 pounds. This represents a total of 7.2 per cent of the plants reporting and 4.5 per cent of the total metal melted. The average life of the linings varies from 700 to 1500 heats in different plants, the composite average being 990. The refractory lining in the heating portion of this furnace is very thin. It wears through due to erosion by moving metal and due to the penetration of molten metal into cracks and pores of the refractory. At the comparatively low temperatures required for yellow brass the linings are quite reliable and long lived, the regular use of such furnaces is at present limited to metal of this character. The use of this type of furnace for melting foundry red metal depends upon the development of a refractory which will consistently and reliably resist penetration at temperatures upward of 2500 degrees Fahr.

Summary

1. It is noteworthy that the average experience with refractories falls far short of the maximum obtainable. In many individual instances the reasons for this condition are rather obvious and a very substantial improvement could be made merely by the application of well known and widely used principles. This applies particularly to the operation of open flame furnaces where average practice is much inferior to best practice. A campaign of education appears to be in order.

2. Many plants, even very prominent plants, keep inadequate records. This is particularly true in the case of pit-type furnaces,

less true with open flame furnaces, while the records kept by electric furnace users are surprisingly complete.

3. The personal element with respect to the installation and maintenance of linings and the operation of furnaces is of prime importance. Variations in this respect are frequently so great as to obscure the effect of all other factors governing lining life. This, again, is particularly true in the case of pit-type furnaces.

4. In the case of electric furnaces an advanced practice is followed with remarkable uniformity and the result is plainly evident in the excellent refractory results obtained. This is due almost entirely to educational work by the electric furnace companies and is an indication of what can be done along this line.

5. The larger the furnace, regardless of type, the more difficult are the refractory problems, although larger furnaces usually succeed in producing a greater tonnage per lining, in spite of their short life expressed in heats per lining.

6. A high rate of production is favorable to long life provided the particular refractory used is not exposed to a maximum temperature or fluxing action beyond its capacity to withstand. In certain furnaces the lining life is increased by melting charges of less weight than the rated capacity of the furnaces.

7. In crucible furnaces the nature of the alloy melted is of little consequence except as its required pouring temperature governs the duration of the heat. In hearth furnaces the life of the lining is shorter when melting alloys which tend to produce an excessive penetration of molten or vapor metal into the refractory.

8. The use of fluxes, or the presence of foreign material in the charge, do not affect pit linings, since there is no direct contact. In hearth-type furnaces fluxes are injurious to the lining to a varying extent depending upon the nature of the flux and the quantity used. The presence of oil or water in the charge is also detrimental.

9. It is of utmost importance that hearth-type furnaces should be kept as free as possible from adhering slag and that the methods used for removing slab accumulations should be mild. The use of powerful fluxes, extreme heat in an empty

furnace, or mechanical chipping, are all damaging to the refractory.

10. In pit-fire linings to be used with a solid fuel, the refractory used should have the least possible tendency to soften on the surface in order that it may keep free from adhering clinkers. When oil or gas are used the refractory must be of such a character as to resist the cutting action of the flame and retard penetration of unburned fuel into the lining. In both cases it is probable that rammed linings offer the best line of development.

11. In hearth-type furnaces brick should be used so far as possible. The refractory must have a maximum resistance to spalling and at the same time be dense to prevent penetration by metal or oil. This rather paradoxical requirement is of especial importance in electric furnaces of the indirect-arc type. Resistance to chemical action by slags and fluxes is also of great importance.

12. Carefully preheating the lining is of paramount importance, particularly with hearth-type furnaces. Probably no other one factor has a greater influence on lining life. Glazing the surface of the lining with a wash or slag, before it is put into service, is beneficial in the use of hearth-type furnaces, probably detrimental with pit-type furnaces.

13. Patching linings is an art. It is next to impossible to give definite instruction covering its technique. It can be said, however, that frequent inspection and patching is of utmost importance. In the case of hearth-type furnace linings should be inspected daily and every sign of incipient failure should be corrected by hot patching. Thorough cold patching should be practiced once a week. There are a multitude of patching cements on the market and most of them are good when properly used. Some require more skill in their application than do others. A suitable patch is one which will "stay put" indefinitely and will possess all of the good qualities of the original refractory. Making it stay put is the real problem.

Respectfully submitted,

H. M. St. John, *Chairman.*
Committee on Non-Ferrous Survey.

Discussion

Mr. Stadel: I would like to ask Mr. St. John what he considers the proper length of time for preheating a furnace before putting it in operation.

H. M. St. John: That answer would have to be subdivided into several sections. In other words, what type of furnace?

Mr. Stadel: The Monarch open flame.

H. M. St. John: I think the best result would probably be obtained by keeping a coke or charcoal fire in it over night and then an oil fire, a low oil fire, for four or five hours, and then bring it up to melting heat. About 24 hours, including one over-night period, seems to give the best results. And also, if you glaze the lining, either by putting on a wash that will glaze during the preheating period or by melting a slag and slagging it out, so you have a glazed surface before you charge any metal, that also seems to be of considerable advantage.

F. A. Harvey: I only know a little bit about two types of non-ferrous furnaces, and, as Mr. St. John has said, we have our troubles with those two types. The non-uniformity is a property which we have recognized in our working with both our research department and with the consumer. We have recently discovered one of the sources of non-uniformity and eliminated it, at least, we think we have. The only solution, as I see it, as Mr. St. John says, is continued cooperation between the manufacturer and the user of the furnace. I hope eventually we will get to the place where we can have uniformity, not with the poor users, but with the good.

High Temperature Cement

By H. M. Thompson,* Chicago

Today the combustion engineer can give you as high a temperature in your furnaces as the refractories will stand. Therefore, you will agree with me that anything which will increase the life of furnace linings, or improve them, is of importance.

I do not mean to convey that ability to withstand high temperature is the only characteristic to be considered. Brick should be selected for the special duty required of them and should be laid up with a material that will unite them in a bond of equal strength to the brick, having the same co-efficient of expansion and contraction and capable of withstanding equal temperature without deterioration.

Did you ever consider that a mixture of fire clay and water has absolutely no bonding strength and is not the proper material to use in laying fire brick? Fire brick of a quality best suited to meet the furnace conditions are selected without any careful consideration of the permanent adhesive value of the material to be used in the joints.

The maintenance of furnace linings is a large item in the cost of production. There is not only the cost of repairs or renewals to be considered but the decreased production due to time lost. Usually the falling of an arch, the bulging of a wall or excessive cutting away of a portion of the interior of a furnace, can be attributed to a defect in the joints. The fire clay disintegrates or falls out, allowing the heat to work in between the joints, attacking the lining and shortening its life. Very often an arch is lost due to the clay becoming loosened around one of the roof brick, falling out and weakening the whole structure.

Fire clay does not support the brick. It works loose from expansion and contraction, permits small particles to work in between and gradually widens the spaces until the openings are large enough to admit the circulation of the gases and the result is ruination of the structure.

*H. M. Thompson Co.

Most high temperature cement forms a lasting union between the materials to be joined, sets at normal temperature—that is, air sets, and retains its strength regardless of the heat to which it is subjected. Usually high temperature cements come prepared or tempered, are very plastic, and can be used for dipping or troweling purposes.

Most high temperature cements are of the same nature as the best qualities of fire brick. Of greatest importance is the fact that it gives you a good solid wall every inch of the way—from the inside of the furnace where it is exposed to the high heat, clear through to the outside of the wall where it may never become much hotter than the surrounding atmosphere. This insures a tight wall which will not admit passage of gases or any foreign substance, it strengthens the structure and will withstand the action of expansion and contraction.

Tests have proven that some high temperature cements used as a binder in place of fire clay, when air-set, form a joint as strong as the material united and that their strength is not impaired but increased by the action of the heat. This property makes a wall or structure that cannot be obtained with the use of fire clay. Fire clay must be fused before a bond is accomplished and as the action of the heat does not penetrate to any considerable depth, the effect is only a surface bond—as those of you know who have had experience in dismantling a furnace.

The successful use of crushed old fire brick as a ganister for furnace maintenance is being demonstrated daily. The average foundry throws away better refractories than it can buy. In other words, the old furnace linings which have been subjected to furnace temperatures are frequently thrown away, although both shrinkage and impurities have been removed during the initial use. This old material when salvaged or reclaimed constitutes a higher grade refractory lining than the original brick and will be neutral to the operating temperature at which they have been used.

The outstanding characteristics of old crushed fire brick as compared with the same brick when new, or prepared plastic lining of raw fire clay and commercial crushed fire brick, are (1) less shrinkage and (2) higher fusion point, because the used brick have been cured over a long period of time, when in service.

In many cases furnace wall and roof can be rebuilt and repaired through the use of a high temperature cement as a bond with old fire brick, after it has been crushed to the proper size. Advantages are (1) reclaiming old fire brick, (2) low cost of construction, and (3) longer service from lining.

The first cost of high temperature cement is considerably more than fire clay, but the saving in the long run will show a material balance on the profit side.

Report of Sub-Committee on Simplification of Foundry Refractories

1. *Purpose of Simplification of Foundry Refractories.*

An application of a common sense policy to the manufacture, distribution, and consumption of foundry refractories incident to the operation of foundry furnaces, having as its final object the elimination of excessive variety of products with a corresponding decrease in costs and an appreciable increase in realization.

2. *Benefits of Simplification.*

(a) Added source of supply for the consumer by the elimination of production under special specifications.

(b) Reduction of expense to manufacturer through the elimination of a number of sizes in given varieties which must be kept in stock, resulting in quicker deliveries to consumer. Also a considerable reduction in consumers' stocks.

(c) Improvement in quality and workmanship by manufacturer because of more continuous production on a smaller number of varieties.

(d) Possibility of reduction in cost of manufacture of those items that will eventually comprise the simplified list by reason of such reduction.

(e) Simplification of variety of shapes will lead to reduction in original construction costs of furnaces by substitution of simplified shapes in many cases where at present special shapes are in use.

(f) Simplification should and will result in development of more uniform specifications for each given practice involved. It is generally conceded that the quality of a refractory produced is governed frequently as much by the physical shape of the unit as by the content of raw clay, manipulation, etc.

(g) Less likelihood of error in filling orders, thereby eliminating five or six weeks' delay when special shape specifications are misinterpreted by manufacturer or consumer.

(h) Elimination of waste in experimentation or design.

(i) Less obsolete material.

3. *Description of Existing Conditions in Use and Production of Foundry Refractories.*

When a consumer designs a refractory shape for a given place in his practice, he seldom, if ever, considers the manufacturer, but bases his design and specifications as to quality on an assumption of past experience or on a determination to arrive at satisfactory practices by trial and error. If simplification is accomplished the designer will use shapes simplified in form and highly standardized in quality with the result that comparative practices in various consuming plants can be judged. The old conclusion that each brand of fire brick had some natural inherent and unchangeable merit is a fallacy, and it is equally true that most items of highly individualized furnace design are equally barren of any real tangible results. Consumers should realize that conditions affecting utility of foundry refractories dc not vary in different plants to such an extent as generally supposed. A manufacturer needs to recognize the fact that specific fire clay qualities can be broadly standardized. In other words, simplification should result in a better mutual understanding of the services involved.

Within the refractories industry tentative specifications, for instance, covering malleable iron furnace production, have been formulated and are closely checked to determine their ultimate usefulness. If this effort is to be successful it must be supported by the consumer, and in giving this support the consumer will find himself up against apparent changes in practices which will require accurate analysis. In these instances simplification is recommended in both the form and quality of material. With simplification accomplished and with actual tests available by which quality can be scientifically graded, both consumer and producer

will be relieved of the erratic personal equation which is too frequently used in reaching conclusions.

Both consumers and producers are now paying for a large amount of special equipment and both are burdened with capital charges due to a large number of irregular and unnecessary special shapes. In response to a recent inquiry by the committee, one producer made the statement that he had in stock several acres of special shapes. This facetious answer brings out clearly the costly conditions. Another significant fact appears in the rather widespread distribution and consumption in this phase of the industry and the comparatively small size of the producing units. It frequently happens that for a consumer of only moderate size three or four producers are carrying stocks when any one of them is sufficient to meet the consumer's needs. The consumer may think that this burden rests upon the producer, but ultimately the consumer pays. Where stocks become obsolete it is a safe assertion that the loss is about evenly divided among the consumers and producers.

4. *Method of Simplification.*

The committee proposes to review in detail the sizes used in the following specific itemized cases and add to this list as the work progresses:

(1) *Open Hearth Furnaces*
- (a) Roof brick.
- (b) Skewbacks.
- (c) Port arch brick.
- (d) Checker brick.
- (e) Flue tile.

(2) *Sleeves, Nozzles, and Stopper-heads.*

(3) *Malleable Iron Melting Furnaces*
- (a) Bung arch brick:
  1. Wind bung.
  2. Charge bung.
- (b) Tapping hole block.

(4) *Air Furnace Foundries*

(Have solved problem by using standard brick.)

(5) *Gray Iron Foundries*

(a) Cupola linings.

Respectfully Submitted,

Sub-Committee on Simplification of Foundry Refractories,

W. J. Corbett, *Chairman,*
H. R. Colwell,
J. M. McKinley,
E. M. Weinfurtner,
L. C. Wilson.

Discussion

H. R. Colwell: Mr. Chairman, I regret to say that Mr. Corbett is unable to be present at this time. I have a brief report which was prepared by our sub-committee on simplification of foundry refractories. It covers the purpose of simplification of foundry refractories and the benefits to be derived. A description is also given of the existing conditions in the use and production of foundry refractories.

The fourth paragraph of the sub-committee's report seems to be of particular interest and it contains the proposal to review in detail the sizes used in the following specific itemized cases:

1. Open Hearth Furnaces.
   (a) Roof brick
   (b) Skewbacks
   (c) Port arch brick
   (d) Checker brick
   (e) Flue tile

2. Sleeves, Nozzles and Stopper-heads.

3. Malleable Iron Melting Furnaces.
   (a) Bung Arch Brick:
      1. Wind bung
      2. Charge bung
   (b) Tapping-hole block

4. Air Furnace Foundries.
   (Have solved problem by using standard brick.)

5. Gray Iron Foundries.
   (a) Cupola linings.

In other words, they have met several times, have formulated a procedure that is a very comprehensive and a very good program. Our progress has been rather slow and perhaps something will develop that will enable us to make greater progress.

. MR. WILLIAMS: I do not presume to know very much about foundry practice, but I do know something about the manufacture of sleeves and nozzles. You are aware that there are a great many different shapes and sizes, all of which require dies. These dies must be made accurately to insure ware produced meeting the consumers' requirements, and work of this nature is costly.

All production men know that in order to produce efficiently, jobs must be of sufficient size to keep men, or gangs, assigned employed continuously throughout the day. And so when the manufacturer is compelled to shut down his machinery during the regular working hours because the required quantity has been made, he loses about nine man hours, while a different die is being set up. You readily appreciate what it would mean to have several changes in a day.

Dies wear very rapidly because of the abrasive nature of the clay, and it is obvious that where the quantity of ware to be made will justify the expense, that dies can be constructed of material to better meet this abrasive action. Then again, we are all interested in the development of new and better machinery which is capable of producing a high grade ware at a lesser cost. Such development is only possible when production is standardized.

As practical men, you appreciate the care that must be taken to produce perfect sleeves and nozzles from clay, without which much that is now common practice would be impossible. Therefore, you are interested in anything that places at your disposal a better grade of ware on shorter notice.

MR. OWEN: Mr. Chairman, it is hard to add anything to what Mr. Williams has already said, except to substantiate it. If I should say that we alone have been making a sleeve and nozzle line and have probably 100 different sizes of sleeves and over 100 different sizes of nozzles, and that you other manufacturers probably have more than that, it is very obvious that there are too many different sizes being used and that there is a very large field here for simplification and standardization. For the benefit of the practical men, it seems to me that if they go to standardization and they are a little bit cautious or want to be a little bit cautious as to the first move they make, because there are so many different dimensions that are involved in sleeves, that diameters are the first things. This is because they right away affect the larger pieces of your dies, your big members of the die equipment. It doesn't matter so much the length of it or even the change to the female or male joint of the different members. So if you are going to start in on that and are a little wee bit cautious, start right in and come to some standards, about four or five standards, on your

diameters, that is, your outside diameter, and then your inside diameter. There you will solve, I would say, 60 per cent of the difficulty right there. Then it is easy to cut some of those sixteenths out and standardize on female and male joints or the bowl of the nozzle or the snout of the nozzle, etc. Something certainly should be done. I would think if we could design probably 3 sleeves and 6 nozzles, it would answer every requirement there is. I have a lot of data on that but I just got in on this thing today. I would be glad to work with that committee and give them the benefit of our experience and give them a lot of this data that we have compiled.

CHAIRMAN L. C. HEWITT: We welcome your cooperation, Mr. Owen. I can see that your experience is verified by ours. I had a resume made of various types of dies that we had on sleeves and nozzles and we have dies on 75 different types of sleeves and 112 nozzles. A number of these are almost identical, just some slight change. There is no reason why one design cannot replace a great many. It is obvious where you have your materials standardized and manufacture them in large units and have them in stock, it is of benefit both to the producer and the consumer.

H. R. COLWELL: Mr. Chairman, I am not well acquainted with the technology of this specific industry, but it seems to me in my contact with other industries—and I don't think this industry is in any way different than a lot of other industries, that they all have the same fundamental principles of production, etc., but in other industries we are able to carry forward a simplification from the time the committee is appointed and in from 3 weeks to 6 months have a complete simplification. Now, I have read to you the work that this committee contemplates, and I am very anxious to have Mr. Owen added to this committee, for the reason that he readily grasps the idea of simplification.

If we could just start on one thing and get that done, at the revision conferences of the industry we could add additional simplifications, and thereby in a space of a few years we would probably complete the job.

CHAIRMAN L. C. HEWITT: Mr. Colwell's point is very well taken. It seems necessary to pick out some particular point and work on that rather than attempt to cover the entire field at once. We hope to put into the field before long a man who will make more specific studies and obtain more accurate information than we have at present on those features.

C. N. RING: I have nothing particularly to add except to say that as a man in the consuming end of refractories I have had experience in steel foundries for the past 25 years and I know we are perfectly ridiculous on the number of sizes and shapes we have on sleeves, stoppers and nozzles at the present time. In order to bring this home to the foundrymen at the present time, I have arranged downstairs an exhibit of 8 stopper rod assemblies from 8 different steel foundries in the United States producing

heats of approximately the same tonnage, and by going down and looking at the assemblies, you couldn't tell the difference between one assembly and another, in any way, shape or form. We have a composite drawing there of the 8 assemblies, the members of them, showing there is very little differences between them. We also have secured from one producer the number of sleeves and nozzles he is compelled to manufacture to supply his trade, and the same way with the stoppers. I am perfectly satisfied that with the 8 assemblies that we have down there either one of these 8 companies could adopt that one particular assembly there and it would answer their needs. I think at the present time in the steel foundry industry the decision as to the size and shape of sleeves that they want is left entirely up to the man who is in charge of their ladles, making up their stoppers and pouring their heats. If he has been going along for a considerable time and having no trouble from leakage, etc., they just leave it up to him to get what he wants. There is no specific reason why they have adopted a certain size or shape with reference to diameter or length or size of female or male portion.

This campaign for simplification of sleeves, nozzles and stoppers had its start about 4 years ago, at which time we had a meeting at the Department of Commerce in Washington and it seemed for the time being that we had a fair start here, but it has petered out, simply because there has been no one behind it pushing it. We thought some months ago when we formed this Sub-Committee on Simplification and Standardization we might get somewhere. I also feel that at the start we might limit our endeavor to sleeves, nozzles and stoppers, and probably limit ourselves, as suggested, to dimensional limits first.

J. R. Allan: To add a little fuel to the fire, our committee happened to get hold of about 200 blueprints of tapout blocks and slag-hole blocks for cupolas made by one refractories manufacturer. We would like very much to turn that over to the committee on survey conditions in the gray iron industry.

Mr. Owen: Just one more word that came to my mind. I don't know the tonnage represented by the American Steel Foundries nor do I know if any of their men are here today, but I do know that they are one of the largest of the steel foundries and have at least six very large plants, and they use only one bottom sleeve, one middle sleeve and one nozzle, of course, with the exception that they have that one nozzle with five different holes to suit the sizes of their heats at the different foundries.

Centrifugal Tube Casting in Hot Molds

Leon Cammen,* New York City

The use of hot molds in centrifugal tube casting is a matter of necessity, not of choice. Where the metal is of such a character that it can be superheated without injury, and where the weight of the casting is large, all that is necessary is to maintain the mold at a temperature (approximately 350 degrees Fahr.) at which no deposits of moisture can form thereon. Where, however, the amount of metal cast is small (e. g., in tubes of small diameter, 3.5 inches inside diameter and 4.25 inches outside diameter for blanks used in making hollow billets for drawing small tubes), and the length of the casting considerable (e. g., 60 to 90 inches), metal delivered to the mold from one end (there being no room to use a long spout) simply will not flow in a mold that is merely warm.

The writer, in his work, encountered many instances where, through some trouble in handling the hot mold, the latter was colder than it should have been at the time when the metal was teemed. The invariable result was that the tube cast was too short as it did not fill the mold from end to end.

Except from the patent point of view, it does not matter how the mold is heated. In the Stokes and Hurst-Ball methods (used only with cast iron), the molds are kept hot by making one casting after another at such a rate that the mold is maintained at the desired temperature. This is, of course, the ideal method where it can be used, as it eliminates the external heating of the mold and the rather bothersome handling of the big hot mold body between furnace and casting machine. This process is, however, applicable only to cast iron and only to the castings of tubes which are either of very large diameters, or compensate for the smaller diameter by being short. This is due to the fact that where long tubes are cast of small diameter, the contraction on cooling is so small that it becomes necessary

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to let the casting cool quite materially before the necessary force can be applied to effect the stripping. Where this is done, obviously, the mold will become too cold to handle the next casting, and re-heating by external means other than the metal of the casting becomes necessary.

There is another feature, applying particularly to steel and special ferrous alloys of low carbon content, which also contributes to the necessity for using a very hot mold in centrifugal tube casting (in this connection attention must be called to the fact that the present paper deals exclusively with *tube* casting, as conditions are entirely different in the newly developed art of centrifugal *bar* casting). Assume that you are casting a steel tube, to be used as a hollow blank for a seamless tube mill, 8 feet long, 10 inches outside diameter and 7.5 inches inside diameter. The weight of metal in such a tube is so large that, with a spout extending into the mold for a distance of say 4 feet, there is no trouble to deliver metal in such a manner that a tube of uniform thickness from end to end will be formed even when the temperature of the mold is only 350 degrees Fahr. This does not mean, however, that the tube will be good. As the first metal is delivered against the fairly cold wall of the mold, it forms a thin tubular shell which immediately contracts on cooling, with the result that the cast tube lies loose in the mold. This condition is aggravated still more by the fact that the mold, heated by the contact with the very hot metal, expands. The result of the combination of these two conditions is that the cast tube, while subject to centrifugal stresses in the process of its formation, receives no support from the mold. The centrifugal stresses in this case are fairly large, 75 to 100 pounds, per pound of metal cast, while the mechanical strength of the shell of a centrifugally cast tube, with molten metal all the time coming on top of it, is naturally low, and cracking of the cast tube results.

The above explains why tubes cast in cold molds as a rule crack longitudinally and not radically. The centrifugal stresses in a tube in the process of being cast are essentially the same as those produced by water pressure in a cylinder, and it is common knowledge that that is why cylindrical boilers are usually

single riveted in the circumferential seams and double or triple riveted in the longitudinal seams.

This cracking does not occur in casting in a highly heated mold, first because the casting does not contract away from the mold until after the spinning has ceased, and second, because the mold itself is so hot that contact with the cast tube does not produce expansion to any material extent.

Materials for Heated Molds

The securing of materials for heated molds in centrifugal tube casting is not an easy matter, because such molds must satisfy several requirements. In the first place, the mold must not scale and waste away because of the constant application of heating. Next, the mold must retain sufficient mechanical strength at temperatures of the order of 1300 to 1600 degrees Fahr., at which temperatures the strength of cast iron is negligible. Not only must the mold material retain its mechanical strength, but it must also retain its hardness, as otherwise the rather rough handling between the furnace and casting machine would throw the mold all out of shape. Only such alloys as ni-chrome and the high chromium-iron alloys, such as Becket metal, can satisfy this condition. These metals retain practically their full hardness up to a certain temperature limit, which varies from 2000 to 2250 degrees Fahr., depending on their composition, and then somewhat suddenly collapse completely. Next, the coefficient of contraction of the mold material must be not higher, but if possible lower than that of the cast tube. In cold mold centrifugal tube casting, the cast tube contracts while the mold is being warmed and expands, both actions helping to free the cast tube from the mold and facilitating stripping. In hot mold casting there is no expansion of the mold through heating, and mold and casting go through the same temperature reaction. If then the mold on cooling should contract faster than the casting, there will be an obvious danger of gripping of the cast tube by the mold, which would make stripping the tube impossible. Nichrome, for example, has a higher coefficient of contraction than steel, which makes the use of ni-chrome molds, notwithstanding

their excellent thermal properties, undesirable. The rate of contraction of Becket metal is approximately the same as that of steel.

There is one more requirement which none of the materials previously enumerated satisfies, and this is, ability to withstand with impunity the terrific temperature of molten steel. To be capable of this, the mold material should be such as to melt at a temperature far above that of steel, and there is none that could be used for mold making that would do this.

Experiments to Develop Mold Material

In an effort to obtain such a material, a series of tests have been undertaken since 1921. The extremely high melting point of tungsten naturally directed our attention to this wonderful material, and after a certain amount of rather strenuous work, we have succeeded in finding a method for melting it without oxidation or absorption of hydrogen. We have never succeeded, however, in melting more than 4 pounds at a time, and while we have obtained little ingots that we are using for drawing wire, we have come to the conclusion that it would not be possible to melt by this process the thousands of pounds necessary to make commercial molds for tube casting.

We next tried a process somewhat similar to calorizing as developed by engineers of the General Electric Company. There was no special trouble in securing some penetration of tungsten into the body of steel when the latter was properly selected as to analysis, but, while certain otherwise interesting properties were imparted to steel so treated, the melting point of the metal was not affected to any appreciable extent. We then proceeded to develop a method for creating on the inside of a low carbon steel or wrought iron a lining ⅛ to ¼ inch thick, consisting essentially of tungsten, chromium and some iron. With the somewhat limited facilities employed thus far, we have not been able to line tubes larger than 6 inches inside diameter or longer than 36 inches, but while the manufacturing details remain to be worked out, the problem may be considered as having been solved in its essential features.

Protecting Mold Surface from Solvent Action of Hot Steel

All hot molds used in centrifugal tube casting have to be protected from the solvent action of molten steel. This may be done in several ways. Where an extremely low carbon steel is used, a layer of oxide on the internal surface of the mold will be satisfactory. It is not sufficient, however, where the carbon content exceeds say 0.08 per cent, as there the oxide on the surface of the mold is reduced by the carbon in the steel, gas is formed and as it has no other way to get out except through the metal, blowholes result. These blowholes, by the way, have a peculiar shape, somewhat like pears, with the thin end towards the mold.

The writer has tried several combinations including clay, kaolin, etc., but ultimately came to the conclusion that the best material is castor oil, alone or with enough lampblack to bring it to a molasses-like condition. This should, of course, be applied before the mold is heated. In this connection might be mentioned a curious thing about castor oil which the writer had occasion to note in casting duralumin tubes some years ago. The molds were heated to about 1200 degrees Fahr. after having a coating of castor oil applied to them. When the cast tubes were withdrawn, they had an outside surface as smooth as glass, and *were actually wet with oil.*

Temperature of Hot Molds

There is no general formula for determining the temperature of hot molds in centrifugal casting. It depends on the freezing characteristics of the metal cast, thickness of wall of the cast tube, length of casting, and several other features. As a general rule, it may be stated that it is advisable to teem the metal as cold as possible, even when this means heating the mold to an especially high temperature. When the metal to be cast is "superheated," an enormous quantity of heat is released at the time of freezing of the metal, and there is serious danger of the mold burning out. We had several instances of this in casting stellite which melts at a temperature much lower than steel, but is cast in a superheated condition. In casting monel metal, however, melting some 400 degrees Fahr. higher, we never had a case of a mold burning through.

There is one thing that the writer desires to emphasize in concluding his paper, and that is, that centrifugal casting in hot molds has a certain field in which it *has to be* used simply because we know of no other way to accomplish the same results. It is a new art, less than five years old, and there are still so many problems in it to be solved that it is therefore not to be undertaken by amateurs. In fact, a very high grade of engineering and metallurgical ability is required to carry it on successfully. Some very interesting results have been obtained by centrifugally casting tubes in hot molds; the art is in strong hands, and many of the difficulties in the way have already been overcome, while earnest work is being done to eliminate such other difficulties as still remain.

Some Notes on the Development of the Centrifugal Casting Process in Great Britain and Europe

By J. E. Hurst,* Sheffield, England

The broad principles embodied in the centrifugal casting process are now familiar to most foundrymen throughout the world. Apart from certain exceptions, the centrifugal process is dependent upon the use of a metal permanent mold and on these grounds it is entitled to a place amongst the various permanent-mold casting processes. This is now generally accepted and it is a fact that other permanent-mold processes are now frequently referred to as stationary processes to distinguish them from the centrifugal or rotary processes.

On the basis of actual commercial output expressed in weight of castings produced, it is probable that the total output of castings from the centrifugal process far exceeds the output from any other process of permanent-mold casting. From this point of view it must be conceded that the centrifugal process occupies the premier position amongst permanent-mold casting processes, and for this reason some notes on its development are well worthy of inclusion amongst a symposium of papers on this subject.

Superficially, the application of the centrifugal process appears to be of a limited nature, but closer acquaintance rapidly shows the applications of this process are very much larger than one would suppose. Many large foundries and engineers have been intrigued by the possibilities of this process and have engaged in development work and experiments with a view to adapting the process to their requirements. It is impossible in this short review of the status and development of the centrifugal process on this side of the Atlantic to deal exhaustively with all these developments, as it is necessary to pay more attention to those developments which are in actual commercial operation.

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*Newton Chambers & Co., Ltd., also Managing Director, Centrifugal Castings, Ltd., Kilmarnock, Scotland.

Early Developments of Centrifugal Casting

As far as can be traced, the credit for the origin of the centrifugal casting process belongs to Great Britain and the inventor, Anthony Eckhardt, whose very complete patent was taken out in the year 1809, almost one hundred and twenty years ago. Beyond the fact that he lived in Birmingham we have very little further information of this inventor. From this date to March, 1849, the date of Andrew Shanks' patent, little further was done in the development in the process in this country. Shanks applied himself to the production of cast iron pipes, and a description of his process appears in the Scientific American of December, 1849.

Any mention of the development of the centrifugal casting process cannot be complete without reference to the work of Joseph Whitley. The records of Whitley's work on this process as disclosed by an examination of his many patents taken out from the year 1860 onwards, show his remarkable genius and his keen appreciation of the controlling influences in the successful production of centrifugal castings. The pouring device mentioned in his patent No. 13,204, of 1884, is worthy of special comment. This pourer was of the trough type, equipped with a series of nozzle outlets at equally spaced distances apart. The difficulty of the application of this type of pourer to long lengths (actually 8 feet 6 inches) was at once appreciated by him and was overcome in a very ingenious manner by the application of a reciprocating motion to the trough. The continued reciprocation of the streams of metal issuing from the separate nozzles resulted in the distribution of the metal on the surface of the mold in a series of spirally related subdivisions or interlacing spirals. In spite of the mechanical difficulties with which he must have been faced in the construction of high speed rotative machinery, he succeeded in producing castings 8 feet 6 inches in length, tubes composed of several layers of different varieties of cast iron, and castings in brass and bronze, all of which were exhibited at the Inventions Exhibition in the year 1888. The firm of Joseph Whitley & Co., later Whitley Partners, was founded in 1844. This company is still carrying on operations in Leeds as brass-

founders and undertakes the production of cylindrical castings in brass and bronze by the centrifugal process to this day.

The centrifugal process has attracted many eminent engineers and inventors since this time both in this and other countries. Its greatest success has been made undoubtedly during the last decade in its extensive application to the production of cast iron pipes. The developments of Millspaugh, Sensand and de Lavaud and Moore in America, of Stokes and Hurst-Ball in England, Gelsenkirchen and others on the Continent, are familiar to those interested in this subject.

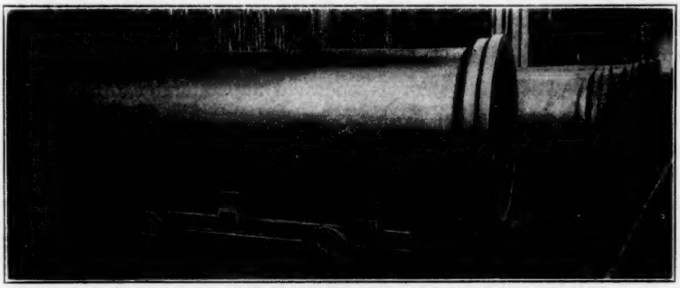


FIG. 1—GROUP OF 33 INCH DIAMETER SPIGOT AND SOCKET PIPE CAST BY THE HURST-BALL SYSTEM

Cast Iron Pipes

The Lavaud process above mentioned is in operation in England at the works of the Stanton company, near Nottingham, and at the works of the Compagnie Generale des Conduites d'Eau at Liege, Belgium. The former plant[1] is the largest unit plant in operation under this system. Since its inception up to November, 1925, it has manufactured and supplied 1,673 miles of pipes. In Germany the Gelsenkirchen company[2] is operating under the Briede patents and other systems are in the development stage.

The process of which the writer is the joint inventor, viz., the Hurst-Ball process, is in the process of development in its application to the production of pipes at the works of Newton, Chambers & Co., Ltd., Thorncliffe Ironworks, Nr. Sheffield.

[1] E. J. Fox and P. H. Wilson, The Foundry Trade Journal, Jan. 21, 1926, pp. 43-48.
[2] C. Pardun, Foundry Trade Journal, Aug. 27, 1925, pp. 175-6.

It is of some interest to note that what is probably the largest centrifugal casting (Fig. 1) yet produced in cast iron, in the shape of a 33-inch diameter spigot and socket pipe, weighing approximately 2 tons, has been made[3] on the Hurst-Ball machine during the experiments at Kilmarnock, Scotland.

The mechanical details of the various processes as applied to the production of pipes have been generally described in various technical publications. The characteristic feature of the Lavaud system is the fact that the pipes are rendered free from chill by subjecting them to an annealing treatment subsequent to their removal from the mold. At the works of the Stanton company this annealing treatment is carried out in specially designed continuous annealing furnaces equipped with waste heat recovery.

In the Lavaud system as operated at Conduites d'Eau this annealing treatment has been dispensed with and the pipes are produced direct in a freely machinable condition free from chill. A British patent, No. 242617, in the name of this company describes the improvements for "Making unhardened iron castings." The essential feature of this patent is that the mold "is lined with silicon, ferro-silicon, or other silicon containing substance" mixed with a suitable adhesive and applied by means of a brush, atomizer or a form of separate pouring trough.

In the Hurst-Ball system the castings are produced free from chill without any annealing treatment. This is effected by using hot molds, the temperature conditions of which are maintained by the actual production of castings. While atmospherically cooled molds are at present in use the correct temperature conditions can be maintained with the use of a liquid cooling medium such as water.

The Chemical Composition of Cast Iron Used in Centrifugally Cast Pipes

The chemical composition of the iron used in the Stanton-Lavaud[4] pipes is as given in Table 1.

The cast iron is remelted in cupolas and is not used direct from the blast furnaces. The importance of the chemical compo-

[3] The Engineer, April 10, 1925.
[4] Fox and Wilson, Foundry Trade Journal, Jan. 14, 1926, pp. 23-26.

sition has been commented upon by the Stanton company and at the present stage it appears to be somewhat uncertain as to whether

Table 1

Element		
Total Carbon	3.5	per cent
Graphitic Carbon	3.0	per cent mean value
Combined Carbon	.5	per cent mean value
Silicon	3.0	per cent
Manganese	.35	per cent mean value
Sulphur	.075	per cent
Phosphorus	1.20	per cent mean value

sufficiently accurate control can be exercised over the composition of direct blast furnace metal for the centrifugal casting process.

In the Hurst-Ball process a No. 3 Scotch iron having a somewhat lower silicon content has been used in the experimental work on pipes. The chemical composition of this iron is that given in Table 2.

The lower silicon and phosphorus contents of this material are responsible for slightly improved physical and mechanical properties.

Table 2

Total Carbon	3.75	per cent
Graphitic Carbon	3.15	per cent mean value
Combined Carbon	0.60	per cent mean value
Silicon	2.75	per cent mean value
Manganese	0.75	per cent mean value
Sulphur	0.075	per cent mean value
Phosphorus	0.75	per cent mean value

Strength Properties of Centrifugally Cast Pipes

The strength properties of pipes cast by the Lavaud process have been exhaustively investigated by Fox and Wilson of The Stanton Company.[5] The tests made by these investigators were carried out on actual pipes and on the material itself. Actual pipes and samples cut from pipes were tested to destruction under different systems of loading, viz.: (1) internal bursting pressure, (2) external collapsing pressure and (3) transverse bending. Specimens of material cut from pipes were also submitted to transverse, direct tensile and other tests. A summary of the

[5] Fox and Wilson, Foundry Trade Journal, Jan. 21, 1926, pp. 43-48.

test results obtained and a comparison with sand cast pipes is included in Tables 3 and 4.

As a result of the improved mechanical properties the Stanton Company has been able to reduce the radial thickness of the centrifugally cast pipes below the British standard specification requirements to such an extent as to produce pipes 20 to 25 per cent less in weight than the British standard requirements.

Table 3

MECHANICAL TESTS ON PIPES*

Centrifugal Cast Pipes

Internal Pressure Test			Modulus of Rupture	Transverse Breaking Test		
Diam. of pipe inches	Bursting pressure pounds	Calculated tensile tons per sq. in.	External pressure pounds	Breaking load pounds	Deflection at center inches	Modulus of Rupture pounds
6	2,800	12.75	54,767	31,400	1.13	45,600
8	2,500	13.30	53,595	50,400	0.80	41,000
10	2,250	13.58	55,257	77,300	0.82	41,400
12	2,000	13.46	52,081	103,000	0.64	34,050
Sand Cast Pipes						
6	2,050	6.94	.....	21,000	0.97	27,200
8	2,200	8.87	.....	33,600	0.62	21,600
10	2,050	9.58	.....	76,100	0.64	26,600
12	1,550	8.04	.....	100,800	0.55	25,600

Note 1—Sand cast pipes approximately 20 per cent thicker than centrifugal pipes. True comparison is brought out by comparing the tensiles and the moduli of rupture rather than actual breaking loads.

Note 2—Transverse tests performed on pipes 12 feet long at 10 feet centers. Load applied at two points 4 feet apart at equal distances from end supports.

*Fox and Wilson, Stanton-Lavaud, Foundry Trade Journal, Jan. 21, 1926.

Table 4

TESTS ON PIPE MATERIAL (Fox and Wilson)

Mean Values in All Cases

	Centrifugal	Sand
Modulus of rupture...............	59,768 pounds	45,025 pounds
Modulus of elasticity.............	15,870,086 pounds	**13,910,000 pounds**
Equiv: Load on 2" x 1" x 36" bar.	41.30 hundredweight	29.3 hundredweight
Direct tensile strength............	18.71 tons per sq. in.	10.37 tons per sq. in.
Tensile strength from ring test....	18.86 tons per sq. in.	10.80 tons per sq. in.

It is of importance to bear in mind that the mechanical test figures above have been obtained on material cast by the Lavaud process after having been subjected to the standard annealing treatment. Certain of these figures are interesting to compare with those obtained on direct castings by the Hurst-Ball system without any annealing treatment.

Apart from the improvement in mechanical properties the use of the centrifugal process is accompanied by considerable improvements in the quality of the pipes. As a result of the

centrifugal pressure the pipes are free from blowholes and internal defects, and the use of a metal mold results in the production of pipes of greater uniformity and to closer limits of dimensions. Even in large diameter pipes, upwards of 2 tons in weight, a maximum total variation in weight of 2½ per cent can be maintained readily. The absence of sand as a molding material also tends to increased soundness in the castings and the pipes are invariably free from adhering sandy skins.

General Cast Iron Castings

The centrifugal process has been extensively developed in Great Britain for the production of cylindrical castings in cast iron for the manufacture of piston rings, sleeve valve liners and engine cylinder liners.

The production of castings by the centrifugal process for the above purposes has been in operation on a commercial basis in Great Britain for the past ten years. As far as the writer is aware this application of the centrifugal process has been developed more extensively in this country than any other.

As in the case of pipe casting, permanent metal molds are used and in all cases the castings are produced directly machinable without any subsequent annealing. In all cases the rotating molds are maintained cool naturally, or atmospherically, and as far as the writer is aware water cooling of the molds or any other form of cooling other than atmospheric has not been utilized for this purpose.

To meet the requirements of piston ring makers, drum castings are made from 2 inches up to 48 inches diameter. A complete range of standard sizes of drum castings within these limits has been drawn up which is practically accepted by all the manufacturers of piston rings. The standardization of the castings enables the centrifugal process to operate on economic lines.

In addition to piston ring drums other varieties of cylindrical castings are produced in a similar manner. Among these are sleeve valve liners for the various types of automobile engines, piston valve liner castings for locomotives, cylindrical liner castings for locomotives, gas, oil and Diesel engines. A photograph

showing a typical group of sleeve valve liner castings produced by the Hurst-Ball process is illustrated in Fig. 2. This process is able to produce cylinder liners up to 36 inches diameter by 120 inches long.

Chemical Composition of General Centrifugal Castings

The above mentioned applications of general centrifugal castings all belong to the classification of high grade castings in

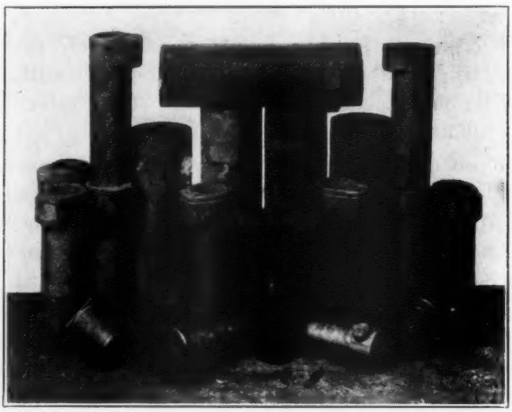


FIG. 2—GROUP OF SLEEVE VALVE CASTINGS CAST BY THE HURST-BALL SYSTEM

which the very best mechanical and physical properties consistent with the particular requirements are desired. The chemical composition assumes a role of additional importance in these cases, as apart from the production of a machinable casting, it is necessary to produce the very best mechanical and physical properties in the castings.

This subject has been extensively studied with particular reference to small castings for automobile piston rings, by a sub-committee of the British Engineering Standards Committee. The physical and mechanical requirements of piston rings are concerned with the ultimate breaking strength of the material and

the absence of "flabbiness" or lack of springiness. In addition to studying the actual breaking strength of cast iron in the form of piston rings these investigations have necessitated a study of the relation between chemical composition, permanent set and modulus of elasticity. A series of tests have been devised for the determination of these properties and a standard specification has been drawn up specifying the minimum limits of these properties which constitute satisfactory piston rings. This specification B. E. S. Specification No. 5004/1924, is also adopted by the British Air Ministry as Specification No. 3.K6. and for further details the actual specifications should be consulted. It is sufficient for the purposes of this review to state that a section has been embodied in these specifications in which the limits of chemical composition for centrifically cast piston ring drums has been specified. The mechanical and physical tests required in the

Table 5

Element	Per Cent
Total Carbon	Not more than 3.5
Combined Carbon	Between 0.45 and 0.80
Silicon	Between 1.8 and 3.0
Manganese	Between 0.4 and 1.2
Sulphur	Not more than 0.12
Phosphorus	Not more than 1.00

specification are the same for both sand and centrifically cast piston ring drums. The limits of chemical composition for centrifugal castings are those given in Table 5

In actual practice the lower limits of the specification as far as silicon contents are concerned are worked to and a typical composition of the writer's own product shown in Table 6.

It is important to add a note that this composition is confined to automobile piston ring drums which castings never exceed 10 millimeters in radial thickness. These castings are produced directly from metal molds without any annealing and are capable of being machined at a guaranteed minimum machining speed of 30 feet per minute. In fact, so far as experiment teaches us at present annealing at temperatures above the pearlite point destroys the "springiness" characteristics. Short annealing at low temperatures of 450 to 500 degrees Cent. improves the springiness.

Physical and Mechanical Properties

The mechanical and physical properties of centrifugally cast piston ring drums are considerably superior to those of similar drums sand cast. A typical series of results obtained are given in Table 7. The additional advantages of centrifugal castings over sand castings for these general purposes are (1) their freedom from sand and hard sandy skins, (2) their uniformity of

Table 6

Element	Per Cent
Total Carbon	3.45
Graphite	2.85
Combined Carbon	0.60
Silicon	2.55
Manganese	0.85
Sulphur	0.09
Phosphorus	0.75

dimensions, (3) the absence of blow holes and internal unsoundness. The value of these advantages in the intensive machining of piston rings needs no further elaboration.

Resistance to Wear

Investigation is in progress on the resistance to wear of centrifugally cast material. It has been found of considerable

Table 7

DIRECT TENSILE TESTS ON CENTRIFUGAL IRON CASTINGS (Hurst-Ball)

No.	Tot. C Per Cent	Si Per Cent	Mn Per Cent	S Per Cent	P Per Cent	Ultimate Strength Tons per sq. in.	Remarks
1	3.21	2.75	0.31	0.11	0.64	17.46	Direct Cupola Melted
2	2.99	2.70	0.39	0.09	0.64	19.40	Metal from Receiver
3	2.95	2.85	0.28	0.10	0.92	19.95	Metal from Receiver.
4	2.99	1.98	0.35	....	....	19.50	Determined on Ring.
5	3.10	2.55	0.29	....	....	19.31	Determined on Ring.
6	3.15	2.75	0.29	....	....	18.71	Determined on Ring.

importance to maintain as high a combined carbon value as possible to obtain high resistance to wear, and on no account should this be less than the minimum value given in the standard specification.

The writer has previously published[6] the results of some experiments on the comparative resistance to wear of centrifugal

[6]J. E. Hurst, Journal West of Scotland Iron and Steel Institute, 1921-2.

and sand cast material. These results are of interest and are given in Table 8. Both samples tested were of the same material from the same ladle, and the tests were made under comparative conditions.

In the initial stages of the wearing action the rate of wear is greater in the centrifugal casting than in the sand casting. The centrifugal casting appears to attain a condition in which the rate of wear becomes of a constant low value, and over the duration of this test the total wear in the sand casting is nearly twice that of the centrifugal casting.

Cylinder Liners

For thicker castings such as large piston ring drums and cylinder liners the thickness of which exceed 0.75 inches a lower

Table 8

CENTRIFUGALLY CAST METAL

	Grams	Grams Loss
Original weight of Specimen	6.7500	
Weight after 3,000,000 revolutions	6.7349	0.0151
Weight after 4,000,000 revolutions	6.7339	0.0010
Weight after 5,000,000 revolutions	6.7335	0.0004
Weight after 7,000,000 revolutions	6.7331	0.0004
Total Loss		0.0169

SAND CAST METAL

	Grams	Grams
Original weight of Specimen	6.7530	0.0075
Weight after 3,000,000 revolutions	6.7445	0.0075
Weight after 4,000,000 revolutions	6.7425	0.0030
Weight after 5,000,000 revolutions	6.7325	0.0100
Weight after 7,000,000 revolutions	6.7220	0.0105
Total Loss		0.0310

silicon content is used. We are able to produce castings directly machinable with a silicon content as low as 1.5 per cent, a value closely approximating that of sand casting practice.

Centrifugal Casting in Steel

The development of the application of the centrifugal process to the production of castings in steel has not been so extensive as in the case of cast iron. There are various reasons for this, of which probably the most dominant is the difficulty of maintaining a continuous supply of molten steel to enable continuous

operation of the plant. This, of course, can be and is overcome, but not with the same ease as in the case of cast iron.

The effect of centrifugally casting steel on the structural characteristics and physical properties of the steel have been ably dealt with in the Bureau of Standards Report No. 192/1921.

At the present time the only application of the centrifugal process of any magnitude to the production of steel castings in this country is the Davis steel wheel process operating at John Brown and company's works at Sheffield. This process is well known in America and its principal object is to secure a manganese steel tread on the wheel. This is done in a very ingenious manner by the introduction of powdered ferro-manganese into the first portions of liquid metal which enter the rotating mold. By virtue of the rotation this high manganese portion of the steel is finally located in the tread of the wheel. The application of the centrifugal process to the casting of steel pipes, hollow ingots and annular billets for various purposes is undoubtedly engaging the attention of many steel works' engineers and metallurgists. At the time of writing, however, these applications of the process have not developed on any extensive commercial scale.

Small steel hollow cylinders or bushes were produced in this country particularly during the war-time when they were used to a certain extent for aeroplane engine cylinder liners. The commercial requirements of small cylindrical steel bushes does not lend itself to the same degree of standardization as in the case of cast iron piston rings, a fact which has operated against more extensive development in this direction.

Centrifugal Casting in Non-Ferrous Alloys

Supplies of molten non-ferrous alloys, available at almost any instant of time, are not so easily organized as in the case of cupola melted cast iron. As in the case of steel this is one of the difficulties to be faced in the extensive application of the centrifugal process to non-ferrous alloys. Furthermore the amount of work available of a repetition character and suitable for the application of the centrifugal process is limited.

In spite of this there are several applications of this process of an extremely valuable nature to the non-ferrous industry. The

difficulty of producing various brass and bronze sleeve castings sound and free from defects is almost proverbial. The sleeve castings referred to are those used for lining paper mill rolls, hydraulic cylinders and rams, pump liners and similar items. These latter have been produced consistently in this country for many years and the ability to produce these castings free from pinholes and similar defects is an outstanding advantage of the centrifugal process.

Some work is also being done in this country in the application of the process to the production of phosphor bronze worm wheel blanks.

Generally speaking, with the exception of gear wheel blanks, sand molds have been consistently adopted in the production of cylinders by this process. One of the reasons for this is the lack of repeat requirements. In spite of this the advantages of the centrifugal casting process in the production of sound castings free from defects, which after all is the first and foremost requirement of any casting, is amply demonstrated.

Application to Concrete and Other Materials

While the interest of foundrymen is largely confined to the application of the centrifugal process for the production of castings in metals and alloys, its application in other directions should not be overlooked. Very extensive developments have taken place in Great Britain and Europe in the production of concrete and reinforced concrete pipes by this process. There are various systems in operation in Great Britain of which probably the largest is the Stanton-Hume system. Among the other systems are the Cochrane-Vianini system of Italian origin and Moir-Buchanan system.

The centrifugal process is also very extensively used for lining cast iron and steel pipes with concrete and also with hydrocarbon materials, the basis of which are essentially materials of the nature of pitch and bitumen.

Concluding Remarks

In spite of the fact that we can trace the centrifugal process of casting metals back for at least 120 years, its development on

a commercial basis is largely confined to the last decade. The widespread interest which it has created in foundry and engineering circles and the undoubted superiority of its product over the ordinary sand cast material cannot be denied. These facts taken in conjunction with the fact that its principal field of operation is pipe casting, an industry of a gigantic nature, claim attention for the centrifugal process as one of the greatest developments in metallurgical circles during the post war period.

The centrifugal process is essentially a permanent mold process with one or two exceptions in which the process has been developed on the basis of sand molds. The writer has endeavored to present some of the outstanding points of interest in the development of this process in Great Britain and Europe.

Finally the writer should like to express his appreciation of the opportunity presented to him of representing the centrifugal casting process in this symposium of papers before your association.

Written Discussion—By Giacomo Bargellesi, Milano, Italy

It may interest members to know that pipes of even greater size to that named in this paper have been cast with the centrifugal process. The Soc. An. Franchi-Gregorini, Brescia, Italy, in its pipe foundry has improved the method of centrifugal casting to such an extent that for the last two years it has produced on a practical and commercial scale pipes of one meter diameter and 4 meters in length with the very small metal section of 17 millimeters and weighing only 1600 Kg. This organization has also pipes of 0.8 meter diameter and the great length of 7.5 meters, which, I believe, really are the biggest centrifugal castings ever made.

The same foundry has recently developed a system for centrifugally casting pipes of the smallest diameters as, for instance, pipes with a 100 millimeters, and 3 meters long and with a thickness of 7.5 millimeter.

Durable Molds

By James A. Murphy, Hamilton, O.

At the solicitation of the father of this association, John A. Penton, the writer, contributed a paper* at the Chicago Convention of 1900, describing a rig for the making of potash kettles. The paper was fully illustrated and would be today, as well as then, an outstanding example of what can be done in the way of permanent molds for some classes of castings.

Like the transmutation of metals, the permanent mold has been sought for ages by foundrymen of every clime, but with only very indifferent success. In recent years, the necessary capital has been put behind the project of development and the successes achieved give much promise for certain classes of castings. However, the processes and methods employed have limitations and will always have some, even should most of the unfavorable physical and mechanical features, as we now know them, be eliminated. The development of faster and better molding machinery and other appliances for the more rapid production of castings in the sand mold, is likely to make both the first and ultimate cost of a permanent mold, a great factor against it. The superiority of castings from the iron mold is unquestioned for many uses, but as their first cost is with a few exceptions greater, and is likely to remain so for some time, difficulty is and will be found in selling the product at an excess price over that of sand castings.

The semi-permanent, or durable mold, as the author prefers to call it, has a different field altogether. It is seldom applicable to small or medium work and is not advocated where the molding machine can be profitably applied. We have found it advantageous only on such large work as is made in quantities, large enough to justify the added expense of construction. It has limitations, too, for the configuration of the casting must be such that it can be removed from the mold or the mold removed from it without a complete breaking up in the process. Much ingenuity can often be employed to prevent this and projections can be made on cores which are in turn inserted in iron slip jackets, but as each job is a law unto itself, it must be left to the indi-

*Permanent Molds, Trans. A. F. A., vol. 12, pt. 1, page 55.

vidual judgment of the foundryman immediately concerned. The two jobs shown are only examples of what is and can be done along this line.

The opinion seems to have gained ground in many places that the magnitude of the marine cylinder program that the writer put through during the war years, was the result of permanent

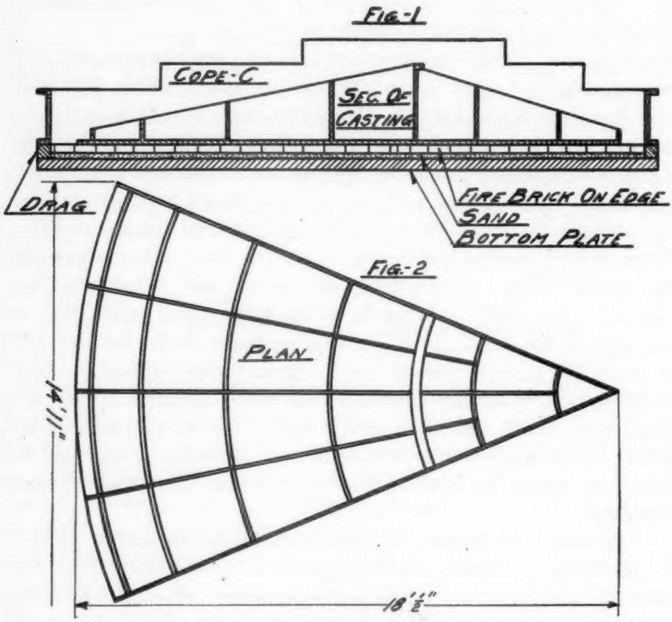


FIG. 1 (upper)—FIG. 2 (lower)

or durable molds. Nothing of this kind was employed and no molding machines were used either.

We have made a great many durable molds, some for a few castings and some for hundreds. Where only a few castings were required, we did not go to much expense, using only an extra plate and a few bolts, or something of that kind. For the larger castings, a fire-brick mold was frequently made, properly

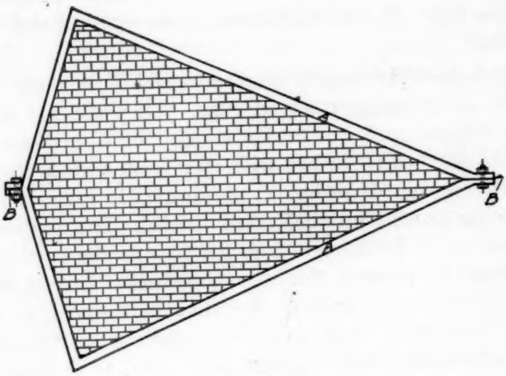


FIG. 3

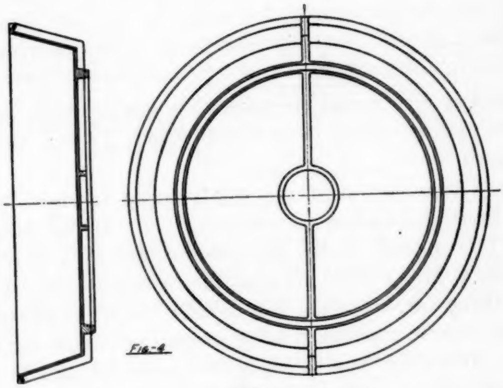


FIG. 4

bolted and secured together, so that copes could be turned over and the whole mold placed in storage for future use, if desired.

Figs. 1 and 2 show a plan and a section of a segment of a plate glass table, 36 feet in diameter, each section weighing about eight tons.

Fig. 3 shows the drag or permanent face of the mold. The fire-brick are laid close together on edge. They are laid on a sand cushion, or bed, and no mortar is used between them. After being laid, the bed is slushed with clay wash and the face of the mold given a coat of ordinary blacking. No loam is used, the metal being poured on the naked bricks. The outline of the bricks can easily be discerned on the face of the casting, but as it is finished by planing, this is no drawback. Indeed, the slight chilling effect of the brick is a distinct advantage, as the face presents a beautiful, clean and close surface when finished. The cope is rammed by hand in green sand and is so arranged by the use of slab lifting cores that not a single gagger is necessary.

This mold has been in use for over 18 years and probably over 1,000 castings have been made in it. It is still as good as ever. The company has practically a monopoly on this class of castings and they deserve it, for not every one will depart from the beaten trail and stand the expense of an engineering feature of this kind.

Fig. 4 is a plan and elevation of a gas producer pan made in halves, approximately 14 feet in diameter, 2 feet 6 inches deep and ⅞-inch thick.

Fig. 5 is a section of the mold, shown in such detail that only a short description is necessary: (a) is the drag which remains permanently on the floor, surrounded by a curbing; (b) is the cope which is lifted off after the casting is sufficiently cool. Before lifting off, a spindle seat similar to (c) is bolted on the top in the reverse position, it being properly doweled for accurate location. When the cope is rolled over, a keyed spindle carrying the cam is placed in the seat. This cam serves the purpose of separating the two halves of the casting by 4 inches, so that space for a splitting core is provided. The casting is by this means swept up as though it were a plain round one, the molder paying no attention to the slightly elliptical shape. The sweep arm is in two

parts, the one sliding on the other, the movable member which carries the sweep being actuated by a roller which travels in a suitable groove on the upper face of the cam. The face of this mold is fire brick and a light coat of loam is used each time the mold is used. While the mold is in use, nearly enough heat is in it to dry itself. When the cope is finished, the spindle carrying

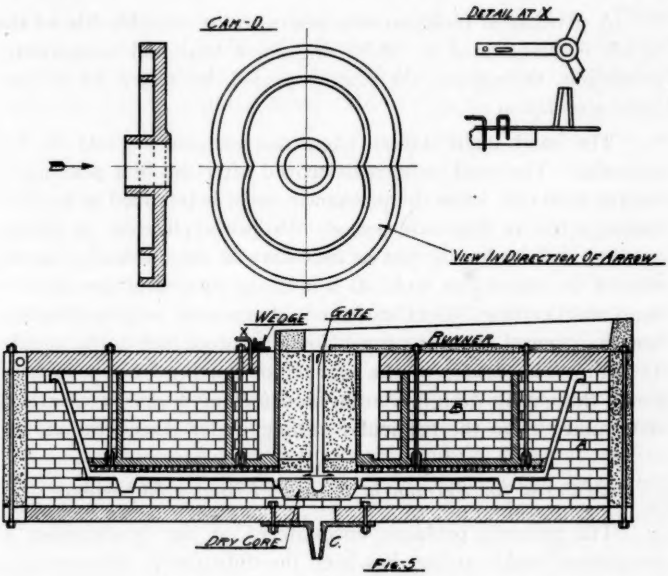


FIG. 5

the cam (d) is set in the step (c) and the drag part finished in the usual way. Over 100 castings were made in this mold, one man casting one every two days. The weight of the casting is about five tons.

Molds in two, three, or more parts could be made from ceramic mixtures, such as is suitable for fire bricks, being burned and treated the same as fire bricks. The contour of the casting, however, must lend itself to such treatment and then it must be made in sufficient quantities, without change, to warrant the initial expenditure.

A Permanent Mold Process

By H. A. Schwartz, Cleveland, O.

A permanent mold process where the serviceable life of the molds is maintained by stabilizing their heat and temperature conditions, throughout the casting period, by means of a regulated circulation of oil.

The sand mold differs from the permanent mold in one essential. The sand mold is destroyed after the first pouring of molten material, while the permanent mold is intended to produce castings for an indefinite period. Proper application of gating, venting and feeding is just as necessary to the successful operation of the permanent mold, as it is to the successful operation of sand mold casting. Details of the two processes may be different, but the general laws of proper foundry procedure apply equally to both. The details of the manner of parting of a permanent mold, the gating design, venting and feeding means, etc., are all determined from the particular casting under consideration.

Material for Permanent Mold of Primary Importance

The primary problem, encountered in the development of permanent mold casting, has been the difficulty in discovering a mold material, or in devising a means, which would enable the permanent mold to remain in a serviceable condition for a sufficient number of pouring operations to make it practical for commercial operation. The problem will be better understood when the conditions are analyzed under which the permanent mold operates.

In practical operation, a permanent mold must form castings from repeated charges of molten material. The rapidity with which these charges of molten material can be poured into the mold determines its relative value commercially.

The heat released from each forming casting is abstracted by the mold over its cavity surfaces in varying quantities, depend-

ing upon the material being cast and its distribution in the casting. If no other means are provided, the heat taken up by the mold is thrown off by surface radiation.

The temperature condition obtaining in the mold depends on the time interval between successive pouring operations, the temperature of the material being poured, and the mass of the casting being cast. To be successful commercially, intervals between successive pouring operations must be very short. Then, under given conditions of permanent mold surface area, the temperature condition of the mold will vary as the temperature and mass of the material being cast.

When pouring materials of low fusibility, such as the so-called white-metal alloys, the permanent mold is best able to cope with the heat input from successive charges of such molten material. When pouring molten material, such as the aluminum alloys, the ability of the mold in this direction is of lesser degree. When casting materials, such as the iron and copper alloys, the difficulties from heat accumulation in the mold are greatest. In such cases, heat from the forming castings is received in successive waves by the mold, and, in uneven quantities at different portions of the mold structure, depending upon the distribution of the casting mass. The mold structure is subjected to continually fluctuating temperatures of widely different degree. These fluctuating temperatures cause violent and constantly changing expansions and contractions in the mold structure. If this condition prevails even for a short period, cracks, checks, and fissures will appear in the mold surfaces. Also, because of the accumulation of heat at and near the mold cavity surfaces, the molten material being poured will fuse to the mold surfaces. In a short time, mold deterioration reaches the point where the mold becomes worthless. Even before this stage is reached, it becomes increasingly difficult to continue casting operations.

Process Developed to Counteract Destructive Temperature Conditions

The process described in this paper was developed to counteract the destructive temperature and heat conditions obtaining

in the permanent mold under operation. Under the process, for the entire period of casting operations, a unified temperature and heat control are maintained in each of the several permanent mold sections making up a casting unit, as follows:

1. To stabilize around a common range within as close limits as possible, the spread of fluctuating temperature throughout the mold structure, so that injurious structural stresses will be reduced to a minimum.

2. To establish and maintain within as close limits as possible, a predetermined temperature in each of the several mold sections, suitable for the material and distribution of same in the casting being poured.

3. To promptly carry off the surplus heat, abstracted by the mold from the forming castings, where and as it is taken up by the mold.

4. To effect, by proper control of the foregoing regulation, a suitable velocity of heat extraction from each of the several surfaces of the forming casting, necessary for the required hardness characteristic in the casting structure.

Cooling Fluids

It was found in the course of the development of the process that only fluids having definite thermal and physical properties at the operating temperatures could be used successfully for the purpose of effecting the required control over the mold temperature and heat condition. For instance, the use of water for this purpose proved to be a failure, for the reason that under the operating temperatures, the hot mold surfaces cause a continual formation of steam films or pockets from the water in contact. Such a combination of water and steam, of widely different thermal characteristics, together with its instability at the operating temperatures, did not have the desired effect of uniform abstraction of heat from and distribution of heat in the mold walls. On the contrary, it was found that the use of water for this purpose actually promoted injurious mold temperature fluctuations.

After a period of intensive experiment with various types of heat absorbing medium, it was determined that certain oils were best suited for the purpose, not only because they had the required properties but because of their availability and ease in handling.

Mold Construction

The permanent molds, operating under the process, are now made of ferrous alloys especially suited to the conditions encountered. Each mold unit consists of the necessary number of sections required for that particular parting, venting and constructional design. The mold cavity walls are made as thin as possible, ½ inch or less, and yet have the strength to withstand the imposed mechanical stresses.

A fluid jacket, through which the heat absorbing medium circulates, encloses the back of each of the mold sections. Fins and baffles are arranged, and cavity wall thickness is varied, at proper points on the back side of the cavity walls, to vary the mold surface area in contact with the circulating fluid and also to create a turbulency in its flow through the fluid jacket. This is for the purpose of promoting or retarding the abstraction of heat from different portions of the forming casting, as well as for the purpose of maintaining a proper temperature control over the mold structure.

Mold Units

The cost of a set of mold sections comprising a mold unit, should not greatly exceed, if at all, that required in constructing a metal pattern for casting a similar casting in sand molds. Mold units are designed so that their over-all dimensions fall into a few standardized sizes.

These mold units are attached in a simple manner to standardized operating mechanisms. One or more of the mold units may be attached to one operating mechanism, depending upon the style of casting being formed. The operating mechanism is of simple but rugged design, and, as a rule, costs much less than a sand molding machine.

Each mold unit, attached to its operating mechanism, is an independent operating unit within itself. As one such unit does not require the constant attendance of an operator, a number of such mold units, about six as a rule, are arranged in one battery and operated progressively by a crew of two men; including the pourer. Each mold unit in an operating battery may be arranged to cast different casting styles, if production so requires. A number of operating batteries are usually arranged in one installation.

Cooling Medium Circulating System

One circulating system cares for the circulation of the heat absorbing medium through the mold sections making up the entire installation. This circulating system consists of a main inlet and outlet pipe for each mold battery, a pump mechanism for forcing fluid through the system, a cooling means to cool the hot oil leaving the mold sections, and a storage tank for storing the cooled oil ready for use again. Gauges, thermometers, etc., control the proper regulation of temperature and flow of the circulating fluid.

Each mold unit is valved and attached to the main inlet and outlet pipes, serving that particular battery, by two union connections. Shutting off of the valves and disconnecting the two union connections, permits the servicing or replacement of any mold unit without interruption to casting operations on the remaining mold units. The flow of oil through the mold sections is controlled by a thermostatic device sensitive to the mold temperature.

As the mold temperature tends to rise immediately following the introduction of molten material, the oil flow is increased to a maximum. After the ejection of the formed casting, if the time interval preceding the next pouring operation is long enough to allow the mold temperature to fall, the fluid flow is reduced and shut off entirely if the mold temperature falls below a predetermined point.

Because the oil remains in a more or less stable liquid condition at the operating temperatures, the convectional currents—created by the circulation of the oil through the mold sections—will maintain the temperature condition of the mold cavity wall

structure in a stabilized range within close limits. By regulated circulation of this oil, accumulations of surplus heat in the cavity walls is prevented and predetermined mold temperature is established and maintained within close limits.

In the majority of cases, the temperature of the cavity walls is stabilized at levels between about 350 degrees to 850 degrees Fahr. The temperature range at any one point on the mold structure does not exceed 75 to 100 degrees Fahr. from the established point. As an example, records kept on a mold casting of a thirty-five pound casting over an extended casting period, indicated a variation from the established temperature point of less than 50 degrees Fahr.

Suitable temperature ranges for each of the mold sections are determined from the character of the material being cast, the type of casting structure desired, and the distribution of material in the casting being made. If cast iron is to be poured, the temperature range of each of the mold sections is established at a higher or lower zone, to retard or to accelerate the cooling velocity of the surfaces of the forming casting; depending on whether soft or hard casting structures are required.

Disposal of Heat From Molds

As is quite apparent, the process does not depend on haphazard disposal of heat from the permanent mold by radiation or otherwise. On the contrary, an effective means is provided to promptly dispose of the surplus mold heat as it is taken up by the mold from the forming castings. Consequently, regardless of the rapidity of the successive pouring operations, or kind of material being cast, or distribution and mass of such material, accumulation of surplus heat in the mold is prevented. This results in the maintenance within safe limits of the mold temperature conditions.

This control, provided for by the process, makes possible two great advantages, not obtainable in other permanent mold methods without such control. First, limitations as to kinds of material, types of castings, and to production capacity, are largely removed. Because of the effective surplus heat disposal, this

process makes it possible to cast a much greater poundage at each pouring, and to pour in more rapid succession, than has been found practical with other permanent mold methods employing haphazard heat disposal. Other commonly used mold methods necessitate the casting of small castings in a large number of small molds operated progressively by a complicated turntable device or otherwise, if over-heating is to be prevented and a respectable production obtained. With the process here described, because of its effective disposal of surplus heat, there can be produced a greater production with a few molds by casting more poundage from each mold at a more rapid rate.

The second advantage, attained through the temperature and heat control exercised, permits regulation of the rate of cooling of the forming casting. When molten material is poured into a permanent mold, the temperature condition of both tend to establish an equilibrium; the rapidity of which depends on the temperature difference between the two, and also on their heat conductive ability.

Contrary to property of the sand mold, the metallic permanent mold is a fairly good heat conductor. By setting up an established mold temperature of suitable degree, and pouring the molten cast iron at a suitable temperature, the temperature difference between the molten material and the mold is so regulated as to produce a desired cooling velocity of the forming casting.

As is now well known, the cooling rate of molten cast iron, as it passes through the solidification stage and critical point, largely determines, and, in fact, controls, the character of the resulting casting structure. It has been proven that, with a given cast iron composition, only a relatively small variation in the temperature difference between the mold and molten iron will alter the rate of cooling sufficiently to result in a marked difference in the degree of graphitization; giving a soft gray iron structure in one case and a mottled or white iron structure in the other.

In a specific test, it was found that a difference of only 150 to 200 degrees Fahr. in the pouring temperature of the molten cast iron would cause a mottled or white iron structure from the higher pouring temperature and a gray iron structure from the

lower. This test was made with sand molds, but, excepting as to degree, it is of equal application to the permanent mold.

Production of Soft Gray Iron Castings

Under the process described here soft gray iron casting structures are produced as follows: As the metallic permanent mold is a much better heat conductor than the sand mold, cast iron formed in the permanent mold is cooled through the solidification stage at a much more rapid rate than in the sand mold. As a result of this quick cooling, the casting structure has a very fine grain with the several elements in a finely distributed state: forming a very strong non-porous casting. Graphitization in a cast iron structure begins after the solidification stage is passed.

Because of the heat conductive properties of the permanent mold, which operates in a beneficial manner through the solidifying point of the forming cast iron, especial attention must be given to the further cooling of the forming casting until it has passed the critical temperature; about 1400 degrees Fahr. for cast iron. This is done by using a cast iron of a composition which promotes a ready precipitation of free carbon.

The pouring temperature is as low as is practical under the casting conditions, to help retard the rate of cooling of the forming casting. The permanent mold temperature is established at a suitable range, depending upon the casting section, to further slow up the rate of cooling.

All these things are done to offset the natural tendency of the permanent mold to rapidly abstract heat from the forming casting. In practice, the castings are separated from the permanent mold as soon as possible after solidification takes place. This permits the further cooling of the newly formed casting down through the critical temperature, at a slow enough rate to allow the necessary degree of graphitization. The ejected castings are permitted to cool as slowly as desired through the critical temperature at a normal rate in air, or at a subnormal rate by cooling within a loose refractory material or within airtight receptacles. It even may be desirable, in certain special instances where the casting has a thin section and is to be used under particular conditions, to send the castings as they are

ejected from the mold through an annealing furnace for a short period, seldom more than an hour or two, as a normalizing action to remove possible skin chill or hard spots. Thermal or electrical means can be provided to register the temperature of the cooling casting in the permanent mold, in order that each casting may be separated from the mold when it reaches a predetermined temperature well above the critical one.

Properties of Gray Iron Castings From Permanent Mold

The free carbon in the gray iron castings produced by the process is in a fine granular form, quite different from the large graphitic plate formation found in the usual sand cast casting. This is true because the rapid rate of solidification prevents formation of a coarse crystalline casting structure and also prevents the larger graphitic plate formation. In comparison tests, with specimens taken from test pieces as well as from castings made by casting from the same ladle of molten iron in sand molds and by the new process, it was found that the new process casting had a deflection, a transverse strength break and an ultimate tensile strength double that of the sand mold cast iron. For instance, ultimate tensile strengths of over 50,000 pounds per square inch have been obtained from permanent mold cast iron of this type.

Yet, with all of this great improvement in the casting structure, permanent mold gray iron castings are very easy to machine. Under production conditions it has been possible to machine cast iron produced by this process at the rate of over 200 feet per minute, with the cutting tools standing up for longer periods than before found possible. The finely divided state of the free carbon undoubtedly has much to do with the ease of machining and increased life of the cutting tools.

Malleable Casting Possibilities

The process should prove of exceptional value in the production of malleable iron castings, not only because of the possible production economies, but principally because of its possibilities in radically affecting the malleable iron annealing methods now employed. The present method of producing malleable iron

requires two distinct steps. First, it is necessary to cast the cast iron with a white iron structure where all the carbon is in the combined form. The hard castings are cleaned and then passed through an annealing process which causes the precipitation of practically all the carbon in a finely divided state, usually called "temper" carbon. A large amount of thought, and time, and effort, has been and is still being devoted in working out an annealing method which will cause complete graphitization in a minimum time without injury to the remainder of the casting structure. With all this effort, present practice requires up to 100 hours or more of annealing time to malleablize a casting. Yet, it has occurred to but a few that this entire fund of annealing practice is based on a cast iron produced under conditions which are anything but exact or uniform.

Cast iron which is to be malleabilized is produced in sand molds, which are poor heat conductors, and whose temperatures vary. As before stated, tests have shown that only a relatively small variation in the pouring temperature of cast iron or in the mold temperature, will result in sufficient change in the cooling velocity of the cast iron to cause substantial structural change. Little attention has been paid to this haphazard condition. Instead, cast iron composition, especially with reference to the silicon and carbon contents, has been so selected that, in even cooling under the most favorable conditions of cooling velocity and poor heat conductivity present in the sand molds, primary graphitization would be prevented. How does this influence the subsequent annealing? Does not such a cast iron composition, developed to prevent primary graphitization under the retarded cooling conditions of sand molds, also work just as hard in making the graphitization in the subsequent annealing operation difficult? Does it not seem that the developed malleablizing practice is based on annealing a cast iron whose composition makes graphitization as difficult as possible?

Primary graphitization of a cast iron structure begins just below the solidification stage, and is controlled by the rate of cooling of the cast iron, rather than by its composition. Of course, variations in the cast iron composition, especially as to the content of silicon or carbon, will require a change in the rate

of cooling necessary to prevent graphitization, but the controlling factor is the cooling rate. It follows then that, if the cooling velocity of the forming cast iron could be controlled, primary graphitization could be prevented without making necessary a cast iron composition with, for instance, a silicon content of less than 1 per cent.

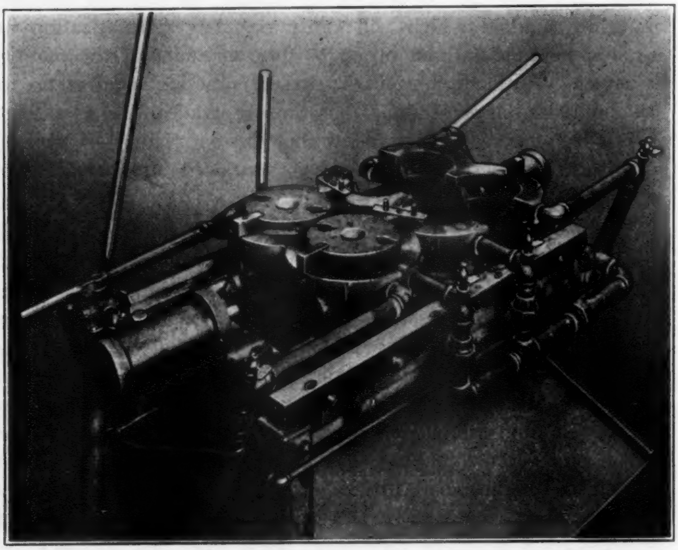


FIG. 1—EXAMPLE OF A PERMANENT MOLD EQUIPMENT FOR CASTING FOUR DIFFERENTIAL MOUNTING CASTINGS AT EACH POURING

The permanent mold does prevent primary graphitization without special attention to the cast iron composition. This is because it is a much better heat conductor than a sand mold, and the process maintains a uniform condition in its heat contents so that its influence on the forming castings is the same at the beginning of a casting period as it is at the end of one.

The ability of the permanent mold to cause a rapid cooling velocity in a forming casting makes possible an extremely fine crystalline state in the resulting casting structure, as the character of the grain structure is determined by the rate of cooling

through the solidification point to about 1700 degrees Fahr. Continued rapid cooling, as attained in a permanent mold casting, will prevent primary graphitization in the formed cast iron. Then, if the cast iron composition is such as will promote rather than retard graphitization in the subsequent annealing, there is no reason why the time for malleablizing a permanent mold casting should not be substantially reduced compared with that now required for malleablizing sand mold cast iron. Experiments in this direction indicate that annealing time may be cut to 10 or 15 hours. In one case, a cast iron containing about 3.00 per cent carbon and 1.5 per cent silicon was annealed in 5½ hours, and showed a tensile pull of about 45,000 pounds, an elongation of about 10 per cent. Of course, this is not up to standard malleable specifications, but it indicates the possibilities.

It is even conceivable, that future development will make it possible, with an efficient control over all the factors influencing cooling velocity, to obtain malleablized cast iron in one operation, by rapidly cooling the forming casting to a point below the solidification point to permit a proper grain structure and then retard the further cooling through the critical temperature at the proper rate or rates to complete precipitation of "temper" carbon.

At present, mold equipment is being installed in one of the large malleable foundries, and it will be operated under production conditions.

Interesting results are expected which should substantiate conclusions formed in preliminary tests in this direction. In tests already made, a permanent mold equipment, as shown in Fig. 1, was operated in a malleable foundry and a number of castings produced. This unit was arranged to cast four differential gear mountings at each pouring.

To show the production possibilities, this mold can be poured, the castings ejected, and the mold prepared for the next pouring operation in less than a minute.

Comparative physical tests, made with mounting castings cast in the permanent mold and in sand molds from the same heat, indicate a marked superiority of the permanent mold casting over the sand mold casting. Photomicrographs of the structure of these castings are interesting. Fig. 2A shows a micro-

graph of the permanent mold casting structure before annealing. Fig. 2D shows a micrograph of the sand mold casting structure before annealing. Fig. 2B shows a micrograph of the permanent mold casting structure after annealing. Fig. 2E shows a micrograph of the sand mold casting structure after annealing. Fig. 2C shows a micrograph of the permanent mold structure near the center of the casting structure after annealing.

A continuous system of melting, or of obtaining molten iron, would have to be used in conjunction with the process, if

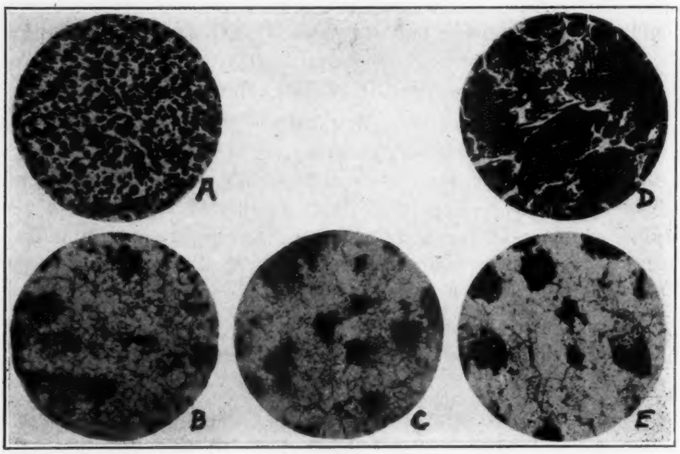


FIG. 2—A, MICROGRAPH OF PERMANENT MOLD MALLEABLE CASTING BEFORE ANNEALING—B, MICROGRAPH OF PERMANENT MOLD MALLEABLE CASTING AFTER ANNEALING—C, MICROGRAPH OF PERMANENT MOLD MALLEABLE CASTING NEAR CENTER OF CASTING STRUCTURE AFTER ANNEALING—D, MICROGRAPH OF SAND MOLD MALLEABLE CASTING BEFORE ANNEALING—E, MICROGRAPH OF SOLD MOLD MALLEABLE CASTING AFTER ANNEALING

full value is to be realized. Several methods are available for this purpose, but will not be referred to here. Where cores are not required, the castings come from the permanent mold in a clean smooth condition. In annealing such permanent mold castings, it will be possible to utilize the heat in the castings when they leave the molds, by sending them through the annealing operation at once.

Some Considerations of Metal for Heavy Iron Castings in Permanent Molds

By H. P. Kimber* and S. M. Udale,* Detroit, Mich.

In the casting of steel in ingot molds, a trouble is experienced known as "piping." A somewhat similar trouble is experienced when a large mass of cast iron cools in a sand mold. This analogy between the problem in the steel works and in the gray iron foundry has been discussed in the British "Foundry Trade Journal" recently as a result of an editorial[1] on this subject.

The elimination of "piping" in steel ingots has been attempted by delaying the rate of cooling of the upper end of the ingot, and also by pouring ingots big end up, and much money and time have also been spent along the lines of the Whitworth fluid compression of steel ingots during the early stages of solidification.

The late Prof. Howe has this to say on the "piping" of steel ingots:

"We shall see that, in solidifying metals in general, the region of last solidification is at or somewhat below the bottom of the internal cavity left by the ebb of the molten, an ebb caused by the different rates of cooling and hence of contraction of the various concentric layers."[2]

"The width and level of the top of the pipe mark the stage in solidification when the contraction of the inner part of the walls and of the molten, taken jointly, begins to exceed that of the outer part of the walls. This width and height are often so great as to indicate that this stage comes very early during solidification. From this time on the inner part of the walls should remain under tension, thus lacking the pressure which we have imagined to fill the blowholes with segregate. But a certain wave of expansion passes slowly across the solid walls of the ingot, starting when the very outer shell passes Ar_1. This expansion

*Holley Carburetor Co.

[1] *Hot Spots,* The Foundry Trade Journal, vol. 33, p. 163, March 4, 1926.

[2] H. M. Howe, *Metallurgy of Steel and Cast Iron,* page 157.

of the subcutaneous layers, after this wave has passed beyond the outer and most rigid ones, together with the pressure from the evolving gas, may give the motive force needed for filling the blowholes."[3]

Following the lines of thought thus derived, the authors of this paper have had cast two samples, each weighing approximately 40 pounds, and measuring 4¾ inches in diameter by 9 inches long, of the same iron cast for comparison, sectioned the samples and explored the interior, taking chemical analyses and brinell readings at many points, and also taking a few microphotographs, for the purpose of ascertaining the effect of permanent molds on the structure of the iron.

Fig. 1—A and B illustrates clearly the difference between casting in sand and casting in iron molds when a considerable quantity of iron is to be cast in one solid mass. Not only is the sand cast iron (Fig. 1B) more open in structure, but it has in the upper portion a large cavity corresponding to the "pipe" referred to by Prof. Howe. Immediately beneath this "pipe" will be noticed an area which appears somewhat denser than the adjacent metal, which is probably the iron which was last to freeze. The casting on the left (Fig. 1A) was made by pouring into an open cast iron piston mold with the core omitted and with the groove portion uppermost. The iron mold was heated to between 600 and 900 degrees Fahr., coated with a thin layer of fire clay and covered with a relatively heavy coating of lampblack applied by a flame of acetylene gas.

Fig. 2—A, B and C show three microphotographs (40 diameters unetched) of the upper middle section of the sand casting. A is at the edge showing the characteristic decarburized area, B is midway between the edge and the center, and C is the center of the casting immediately below the cavity.

Fig. 3—A, B and C show microphotographs (40 diameters, unetched) of the permanent mold casting taken from the same locations as in the sand casting. There is no decarburized area at the edge, but the graphite is in an extremely fine state of division. This refinement of grain structure is carried into the very center of the casting. A decided indication of a dendritic structure can

[3] Ibid., pp. 564-5.

be observed in Fig. 3B, the photomicrograph of the iron intermediate between the extreme edge and the center.

The variation of hardness throughout the mass of the iron was next investigated by taking brinell readings over the entire

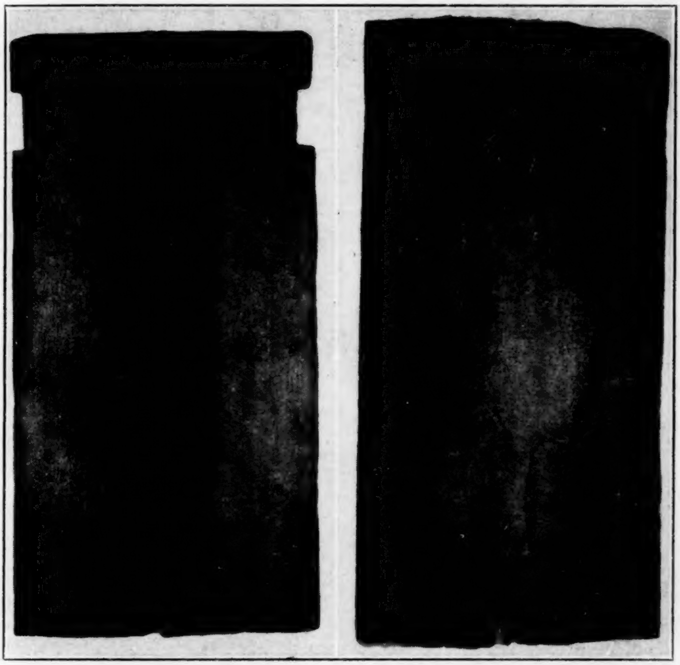
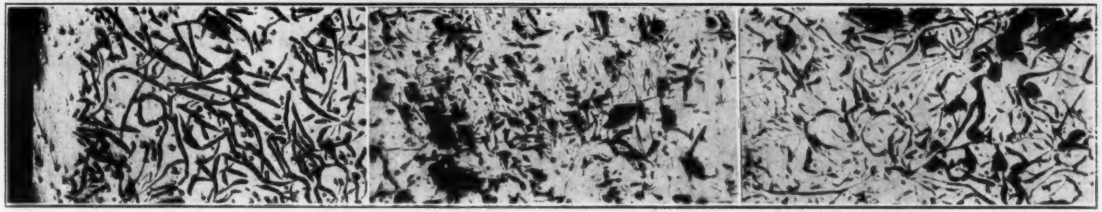


FIG. 1—A, CASTING MADE IN IRON MOLD AND SECTIONED—B, CASTING MADE IN SAND MOLD AND SECTIONED

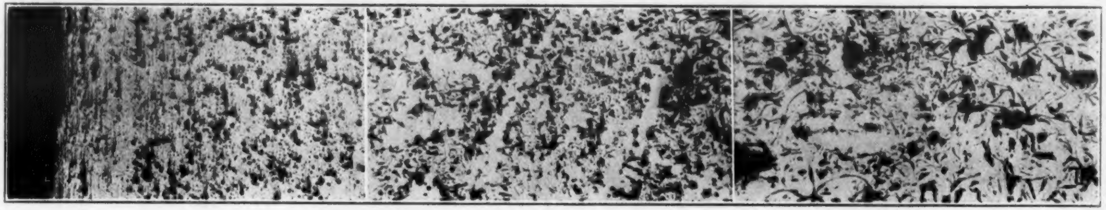
area, as shown in Fig. 4, which shows the results obtained with the iron cast in a heated iron mold. For comparison the total carbon is shown at each above the brinell reading. There does not appear to be any connection between the distribution of total carbon and the hardness variations. The tendency of carbon to segregate in the upper central part will be noted.

The chart to the right, Fig. 5, shows that the brinell hard-



2A 2B 2C

FIG. 2—MICROPHOTOGRAPHS OF UPPER MIDDLE SECTION OF SAND CASTING—A, AT EDGE SHOWING CHARACTERISTIC CARBURIZED AREA—B, MIDWAY BETWEEN EDGE AND CENTER OF CASTING—C, CENTER OF CASTING IMMEDIATELY BELOW CAVITY—UNETCHED 40 DIAMETERS



3A 3B 3C

FIG. 3—MICROPHOTOGRAPHS OF PERMANENT MOLD CASTING FROM SECTION CORRESPONDING TO THOSE OF SAND CASTING SECTIONS—UNETCHED 40 DIAMETERS

ness of the cross section of the iron cast in sand is, except in the center, uniformly softer than that cast in an iron mold. The variation of hardness is remarkably small considering the size of the casting, and the superficial appearance of uniformity is con-

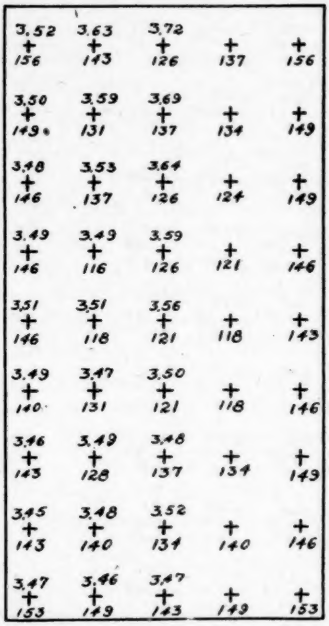


FIG. 4

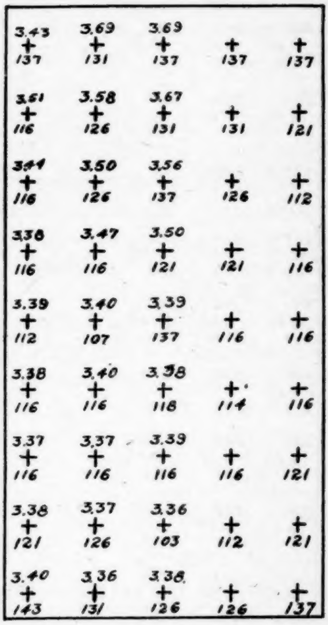


FIG. 5

FIG. 4—BRINELL HARDNESS READINGS OF SECTIONED SURFACES PERMANENT MOLD CASTING—THE FIGURES BELOW THE CROSSES ARE THE HARDNESS READINGS—THE FIGURES ABOVE THE CROSSES ARE THE TOTAL CARBON PERCENTAGES.

FIG. 5—BRINELL HARDNESS READINGS OF SECTIONED SURFACE OF SAND CASTING—THE FIGURES BELOW THE CROSSES ARE THE HARDNESS READINGS—THE FIGURES ABOVE THE CROSSES ARE THE TOTAL CARBON PERCENTAGES.

firmed by the relative uniformity of hardness. Comparing this chart of Fig. 5 with the chart of Fig. 4, one finds that with the sand cast iron the hardness is relatively softer at the edge than the iron cast in an iron mold. It will be noticed that immediately

below the "pipe," in Fig. 5, the hardness is somewhat higher than the surrounding zone (10 to 20 points higher). This dense area immediately beneath the "pipe" is of considerable technical interest.

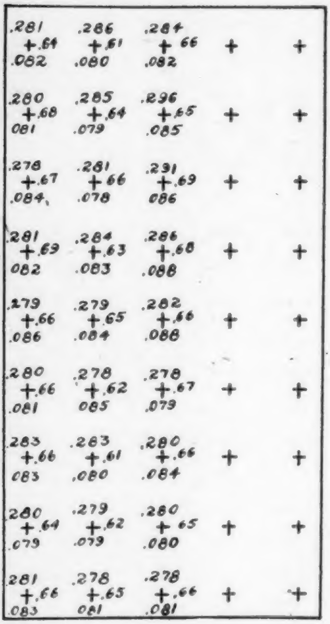


FIG. 6

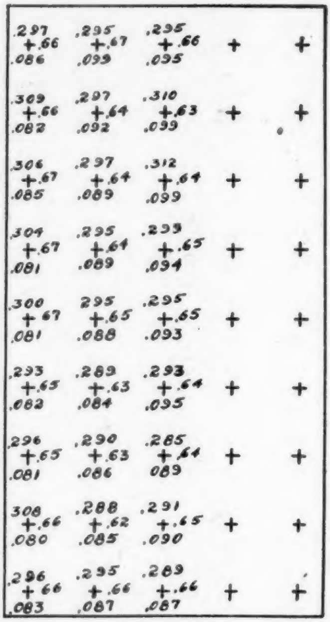


FIG. 7

FIG. 6—SHOWING THE DISTRIBUTION OF PHOSPHORUS, SULPHUR AND MANGANESE IN THE PERMANENT MOLD CASTING—THE PHOSPHORUS READINGS ARE SHOWN ABOVE THE CROSSES—THE SULPHUR READINGS ARE SHOWN BELOW THE CROSSES—THE MANGANESE READINGS ARE SHOWN TO THE RIGHT OF THE CROSSES.

FIG. 7—SHOWING THE DISTRIBUTION OF PHOSPHORUS, SULPHUR AND MANGANESE IN THE SAND CASTING—THE PHOSPHORUS READINGS ARE SHOWN ABOVE THE CROSSES—THE SULPHUR READINGS ARE SHOWN BELOW THE CROSSES — THE MANGANESE READINGS ARE SHOWN TO THE RIGHT OF THE CROSSES.

Fig. 6 shows the distribution of phosphorus, sulphur and manganese in the case of the metal mold casting as compared with the iron cast in the sand mold shown in Fig. 7. There was little evidence of segregation in either case, so that the physical (structural) difference between the two samples is the only real difference. This means that without changing the chemical composition of the iron, we have secured a finer grain, denser metal, and freedom from gas pockets.

In November, 1918, the late E. H. Broughall, of Coventry, England, read a paper before the British Foundrymen's Association, in which he discussed the improvement in the density of the iron which he had noticed when using iron molds. In that paper he pointed out that with permanent molds, not only does one get denser castings due to accelerated cooling, but by utilizing the compression forces created in the interior of the iron due to the property of iron of expanding on freezing, one subjects the freezing mass to great internal pressure. The accepted explanation of this expansion is that the carbon thrown out of solution by the silicon is much lighter than the iron, and hence the total volume of the freezing iron suddenly increases. In our permanent mold casting the cooling rate was greatly retarded by the refractory coating on the mold, so that the grain refinement is mainly due to internal compression.

Like many problems in the foundry, the casting of heavy sections involves consideration of the time effect and the temperature. Unfortunately a complete mathematical analysis of this time effect is extremely complicated and no attempt therefore was made to analyze the problem mathematically, especially as the more concentrated the solution of carbon becomes the lower the heat conductivity.

A comparison between the physical properties of the iron cast in our foundry, when cast in a heated coated iron mold, and the same iron cast in sand is shown in Table 1.

The heat treatment referred to was heating quickly to 1550 degrees Fahr., holding for 15 minutes, then cooling 600 degrees Fahr. in 70 minutes.

As Dr. Moldenke stated more than three years ago, at the

Cleveland meeting of this association, our company has had the benefit of this dense gray iron in its carburetors, and we obtain this advantage along with a definite saving in price. In the development of our process we have taken over parts from the sand foundry, and have never failed to make an improvement in these carburetor parts. We have had to operate simultaneously both the sand foundry and the cast iron mold foundry, and therefore have had to use the same iron for both. Recently we have succeeded in casting in production a large casting measuring about 20 inches by 10 inches and weighing over twenty pounds, this being a vaporizer manifold used on a tractor.

Table 1

CHEMICAL ANALYSIS OF THE IRON USED

Element	Per Cent
Total carbon	3.50
Silicon	2.50
Sulphur	.085
Phosphorus	.275
Manganese	.60

BARS CAST TO THE A.S.T.M. SPECIFICATIONS (15"x 1¼" ROUND)

Type of Test	Sand Cast	P.M. as Cast	P.M. Heat Treated
Brinell Number	184	184	179
Transverse strength in pounds (12" centers)	3,083	4,801	5,024
Tensile strength (Std. A.S.T.M. 8") lbs. per sq. in.	20,970	27,650	26,980
Compression strength in pounds (0.867" dia. x 2¼" high)	52,570	71,400	.....

For those who may wish to go more deeply in to the whole question of the relationship between silicon content, rate of cooling, and physical properties, we refer them to the extremely able article[4] by Emil Schuz, which article is illustrated with micrographs which can only be described as photographic masterpieces. By casting iron containing from 3 to 3½ per cent silicon in a cold iron mold, Dr. Schuz obtained iron having really phenomenal strength characteristics, which strength characteristics were not lost after one hour's heating at between 1450 and 1570 degrees Fahr., which confirms the experiences of the authors.

This work of Dr. Schuz's confirms the very complete investigation of the relation between increasing the rate of cooling by casting against metal chills and the silicon content which was made by the late W. J. Keep's findings which were discussed in

[4] Schuz, E., Stahl und Eisen, Jan. 29, 1925, p. 144.

considerable detail in his book.[5] Professor Thomas Turner also emphasizes the same point.[6] The proper control of the two factors, silicon and rate of cooling, is the key to raising the quality of gray iron and with the quality, raising the status of the whole gray iron foundry industry.

APPENDIX

A comparison of sand cast and of iron cast in iron molds by the process used by the authors gave the following results when the iron used was of the same chemical composition:

Size of Test Pieces 11/13 of an Inch in Diameter by 4 1/4 Inches Long. Tested in 100 Foot Pounds on Olsen Impact Machine

	Sand Cast Iron Foot Pounds	*Holley Cast Foot Pounds*
Not heat treated..........	37	31
Heat treated*	30	67

[5] Keep, W. J., Cast Iron.
[6] Turner, T., Lectures on Iron Founding.
*Heat treatment as described in paper following Table 1.

Permanent and Long Life Molds

By Dr. Richard Moldenke, Watchung, N. J.

Strictly speaking there is no such thing as a "permanent" mold. From a green-sand mold, which may be difficult to hold intact long enough to pour off successfully, to the nickel-chrome steel die from which 100,000 aluminum die-castings are taken, it is entirely a question of how often a mold may be used over again before it is damaged beyond economic repair. Hence the subject for study really becomes one of devising ways and means of prolonging the life of a mold—whether this be of a refractory material or of metal. The very earliest molds described, of stone, in halves and clamped together, into which molten bronze was poured through a top gate to make swords, were not permanent molds but did belong to the long-life variety.

Development Dependent on Economical Pressure

For many years the inventive genius of men familiar with the founding of metals has been directed to overcoming the heavy labor incident to molding, and doing away with the huge sand piles involved in the production of repetition castings. This, perhaps, not so much from humanitarian motives as to cut the cost of production in the general development of the foundry industry. The usual procedure planned is to make the short cut to an iron mold, carry metal by overhead track to pour off, dump out castings requiring but little or no finishing and have an unlimited number of castings to fill large low-price orders. Labor will have been saved, no sand used and operations conducted in a small space when compared with the room necessary for the same tonnage in the ordinary foundry.

It will be of interest to look at the conditions under which the life of a mold can be increased, and how this is offset by improvements in sand molding, with consequent cost reduction from that side. The problem is much like the old gun armor plate competition, an improvement on one side being soon followed by an equalizing development on the other.

Mold Materials to Be Suited to Metal Poured

The art of founding covers the making of castings of many metals and alloys, and in the selection of the material for, and the preparation of the mold itself much depends upon what molten material is to go into it. In other words, the destructive properties of the molten metal must be properly gauged and the mold made to stand it. The chief factor to be reckoned with is the comparatively high temperature range involved, and this range might be scaled to begin with the pouring temperatures of the base alloys, such as white metal, zinc, alloys for die castings and the like. Next upward would come the aluminum pouring temperatures; then brasses and bronzes, cast iron, and finally steel.

It may readily be seen that molds made of material allowing just one pouring of cast iron might serve as long life molds for aluminum, and be very nearly "permanent" for the lead alloys. Indeed, were it not for the further destructive property of all molten materials—the penetration of the mold surfaces by fine filaments, damaging them when shaking out, ordinary sand molds might be arranged to serve repeatedly for the lower portion of the temperature range under consideration. As it is, however, mold surfaces that are practically impenetrable must be provided if the mold is to be used repeatedly, apart from the question of refractoriness. Hence the usual short cut to the steel or cast iron mold.

Possible Materials

On the score of resistance to high temperatures only, the following progression of refractoriness in molding practice would appear to be the case:—Molds of plaster of paris, metal, coated metal, ordinary molding sands and finally molds of steel sands. Before discussing the effect of the mold on the metal poured into it, it will be interesting to note the effect of the metal on the mold. All of the materials just given can be used in the case of the lower range of pouring temperatures without damage to the casting resulting from the effect of heat on the mold.

Even brass can be cast into plaster of paris molds when well vented with asbestos fibre. This is the nearest approach

to the accuracy of a die-casting in actual practice. However, if molten iron be poured into such a mold, decomposition sets in at once, and the steam and gases formed ruin the setting metal for purposes of serviceable work. The accuracy of plaster molds is therefore not available for the higher ranges of pouring temperatures, such as found with cast iron and steel.

Practical Mold Materials

Continuing the subject of mold destruction, we have the following progression from short life to long:—The green-sand mold would appear the most easily destroyed, as it is never used more than once. Dry-sand is better, as on occasion copes have been used again; and with loam records of mold portions being used over a dozen times or so are common.

When core-mixtures form the mold surfaces we begin to get into longer life molds, as these would include such refractory materials as molded carbon—a favorite material for long life molds that will be remembered by many of the older foundrymen as having been used in their early days. The attempt is made here to overcome the penetration of the molten metal into the pores of the mold surfaces, as well as make them resistant to the washing action of much molten metal passing a given point, as at the gate.

The next mold surface in the progression from short life to long is the coated metal mold, in which one of the reasons for applying a refractory protection to the metal surfaces is to overcome the washing action of the stream of molten metal hitting the same spot in pouring off. In this case, however, it is necessary that the coating be practically vitrified, or at least of a nature that precludes the evolution of steam or gases. Much of the cutting of the sand in the ordinary mold, at the gate, is due to the decomposition of the clay bond by the continued heating action of the stream of molten metal. It is the point in the mold which gets more heat, longer continued, than any other of the mold surfaces, and such continued heating finally liberates the "combined" water of the clay, destroys its bonding power and allows the sand grains to wash into the mold. An inspection of a pile of gates and runners where weak

sands are used will soon show the lumps of metal on them where sand has been washed away by the stream of molten metal. That sand will be found somewhere in the surface metal of the castings—to their detriment.

The last in the series under discussion is the uncoated metal mold. This may be either of cast iron, cast iron with steel inserts for gates—to resist cutting away metal by the molten iron impact through simple fusion of the skin; and finally steel molds. Much of the experience gained with metal molds is contemporary history, the very last of it, with an all-steel mold of highest grade material forming the basis for the manufacture of centrifugally cast iron pipe. Even with all the care given in the selection of the steel used, the continuity of operation to minimize expansion and contraction effects, these metal molds are in no sense "permanent" ones, but of a very good "long life."

Effect of Mold Material Upon Character of Metal Poured

The final aspect of the subject at issue—and a most important one to the iron founder—is the effect of the mold material upon the character of the metal poured into it, as found in the resulting castings. This involves the rate of cooling, or abstraction of heat from the highly superheated molten metal. The rate is highest when pouring into chillers, and lowest when heated sand molds are used—this for similar sectioned work. The progression of mold material would be about as follows:—Cold metal molds for fastest cooling, then heated metal molds; green-sand molds; dry-sand, loam and cores; and finally heated sand and loam molds, such as are used for obtaining iron castings with a pearlitic structure out of cast iron so low in silicon that it would have been white in fracture in the thinner sections.

Too fast a rate of cooling is not desirable ordinarily with any metal or alloy, but it is particularly bad when gray iron castings are wanted. Hence, the iron founder, other than the maker of specially chilled castings, avoids metal parts of molds wherever he can, is sparing with chills and often where he must use them anneals the castings. It is, therefore, difficult to interest him in a permanent mold proposition as he knows what he will be up against sooner or later if he takes the matter up. The

founder of aluminum, brass and bronze—in fact, the non-ferrous metals generally, does not find the rate of cooling question quite as serious, and needs only get his mold of metal quite hot, to avoid most of the difficulties with improperly constituted metal in his castings. This can be seen in the aluminum die-casting, the making of bronze torpedo tubes in the centrifugal heated steel mold, and many other examples.

In the case of special lines of work, such as cast iron pressure pipe, the iron or steel mold can be used to advantage provided the castings are subsequently annealed. It may, further, be necessary to use special means of supplying the molten metal to the mold, or to remove the castings. Also, it may be necessary to hold the molds within given limits of temperature.

The fact that a steel mold, for instance, has been found possible of use for a particular casting does not make it follow that another steel mold will serve for producing a different class work. Again, even if the metal mold had been satisfactorily adapted to the making of a given item of work in quantity, the life of the mold may be short—through fire-cracks following repeated and very wide changes in temperature on the part of the surface metal—that the development may not be economical.

Trend Has Been to Coated Metal Mold

The trend of experimentation has, therefore, been in the line of the coated metal mold, where it was essential that a metal mold should be used. Here the rate of cooling of the metal poured into a mold, the contact skin of which is a refractory material of rather high grade, is much slower than with a metal mold not so treated. But even here, with the possibility of making soft, though fine-grained iron castings, there is always the chance of occasional hard ones to give trouble in mass production machining. Hence, here also a short anneal for safety.

Smoking the mold in various ways merely serves to protect the refractory coating from early destruction by penetration of metal filaments. The constant patching of such coatings on metal molds takes them from the class of "permanent" and puts them into the category of long life molds.

The success of these coated molds would depend upon a

number of things. If the refractory coating is made heavy enough, the rate of cooling of the molten metal is retarded sufficiently to avoid trouble from hardness where the analysis admits. The thicker this coating, however, the shorter the life, costlier the repairs and more difficult to compete with the ordinary sand mold method. The avoidance of direct contact with attending high temperature transfer at the skin of a metal mold obviates sudden expansions resulting in eventual fire cracks.

Coated molds have given excellent records for small castings, though on the score of economy in the long run, the matter is still an open one. In the case of work, of which pieces can be put into the ordinary snap-flask, even the coated mold cannot be risked to produce an equal number per cast. In such a case a number of coated molds on a turn-table forms the unit of operation, and while running costs may be satisfactory, first costs mount heavily.

Sand and Loam Molds

Coming now to the sand and loam molds, ordinary foundry procedure is the case. The rate of cooling is so slow, as a rule, that hardness need not be feared if proper metal and rational melting practice supervened. In green-sand work, extra damp sand may give the castings a hard skin and other trouble if rammed too hard or if too fine in grain so that its permeability to gases is too low.

Dried-sand molds and properly prepared and dried loam-molds leave the metal poured into them in as good a condition for proper setting and cooling as can be asked for. Machine-molding has advanced apace, and the foundry industry is getting closer right along to the much wanted jobbing-work molding machine. Even if it is necessary to handle ten times the weight of the castings made in molding sand, this may be made a problem in transportation and conducted at surprisingly low figures.

With the coming of very high grade synthetic molding sands, the life of this foundry raw material will be much prolonged, and the cost per ton of castings held down to reasonable limits. With the use of suitable binders much progress has been made with the repeated pouring off of carefully made and dried molds of this kind. Side by side with the coated metal mold

there is to be looked forward to a development of long life molds of the sand variety which will cut the manipulation of sand tonnages very materially.

Future Possibilities

The founder who develops a good long life refractory mold, without metal backing, will at least not have to worry about any uncertain or injurious action of such a mold on his castings. It looks very much, therefore, as if the general proposition of long life molds—not for special cases only—would best be studied from the standpoint of improving present sand-mold practices to get the cost of handling sand down by better sand; the cost of molding reduced by better molding machine systems and the repeated use of molds or parts of molds; the finishing of mold surfaces to give as nearly perfect "peeling" of the sand from the castings made as possible. Much has yet to be done here in the way of improving materials and practice, but it will be done none the less; and the maker of armour plate has thus to watch his rival who makes the gun to pierce it—to use the simile of the early part of this paper.

Heated Sand Mold

The last link in the progression of mold materials as effecting the rate of cooling of the molten metal is the heated sand mold. Although pouring into hot sand-molds is an old procedure, the present wave of quality improvement in cast iron, particularly in Europe, has brought this practice somewhat into the limelight. In Europe, it is a question of cheap labor but very expensive materials, whereas in America the reverse conditions prevail. Hence, while we here are working with alloy additions to cast iron, they attempt to get improved quality by processes involving labor rather than material, and hot sand molds poured off at fixed temperatures with metal of specified composition for those temperatures have been found to yield cast iron of specially good character for wearing purposes. Whether we here will change the direction of our research remains to be seen. The development is given here merely to complete the discussion of the cooling rate of molten metal as affected by the mold material into which it has been poured.

WRITTEN DISCUSSION—BY W. W. WINSHIP,*
BROOKLYN, N. Y.

Silica in various forms is frequently considered as a material in refractory mixtures for making long-life molds. Not alone are such substances as molding sands and silica sands utilized to a greater or less extent as the principal ingredient of such mixtures, but sodium silicate solution is often employed as the binding agent and presumably is more or less satisfactory in the latter role, depending upon whether it is of high-silica or high-alkali content.

The forms in which silica is mentioned as a principal ingredient of these refractory mixtures comprise sands, quartzite, ganister and other native minerals. They all, however, are characterized by an appreciable change in volume at quite moderate temperatures—say from 200 to 600 degrees Cent.—on both heating and cooling and no amount of heat treatment by ordinary methods will remove this inherent defect. As a result mixtures high in natural silica show much shrinkage in drying, premature cracking and spalling and surface disintegration when in touch with hot metal.

There is, however, a form of pure silica commercially available which should be free from the faults just noted. I refer to fused silica, produced in the electric furnace and up to the present time marketed chiefly in the form of chemical apparatus, tubing and other products for technical uses. I have never seen any reference to it as an ingredient of refractory mixtures for long-life molds.

Possessing as it does the smallest expansion of any known material, fused silica grains, substituted for silica sand, quartzite or other silica mineral, should remove any difficulties due to volume change of the unfused silica. Fused silica is now obtainable crushed to any desired mesh, and I believe at prices which at least put it in the class economically with other high grade refractory oxides, carbides, etc.

A second possibility of improvement lies, in my opinion, in the form of the siliceous binding agent frequently employed in these refractory mixtures. Sodium silicate is not a satisfactory

*The Thermal Syndicate, Ltd.

high temperature binder, having an appreciable coefficient of expansion and rapidly losing its bonding power with loss of water upon exposure to high temperatures.

Precipitated gelatinous silica, derived from sodium silicate by acid treatment, is on the other hand an effective bond at high temperatures and appears to possess the same remarkably low change of volume with temperature change as is possessed by fused silica itself. In fact, the principal chemical and physical characteristics of these two forms of amorphous silica—fused silica and gelatinous precipitated silica—appear to be identical.

I have, as you will see, suggested the substitution of fused silica for unfused silica minerals, and of gelatinous precipitated silica for sodium silicate, both with the idea of improving these refractory mixtures for making long-life molds, by reducing the difficulties caused by changes in volume upon rapid heating and cooling. I shall now go one step further.

If my preceding arguments have been based upon solid grounds, a combination of fused silica grains bonded by gelatinous precipitated silica should prove a useful composition, and preliminary experiments made by our company appear to indicate that such is the case.

As far as we have gone, outstanding characteristics of this fused and gelatinous silica combination, of possible interest for long-life mold work, seem to be:

(1) Lowest expansion coefficient of any known product, greatly reducing danger of cracking or breaking on drying, rapid changes in temperature, or direct contact with hot metal.

(2) Formation of the combination at a low temperature, the only requirement in this direction being that the composition must be subjected to an initial drying at a temperature higher than the maximum to which it will be exposed in use. This is simply to dehydrate the gelatinous silica to the required extent.

(3) Complete absence of any oxidizable or readily reducible substance.

(4) Easily molded prior to acid treatment.

(5) Can be obtained in varying degrees of porosity and sur-

face texture, depending on the size of grain used and the proportioning of the grains and silicate in the untreated mixture.

(6) Will apparently be available at a reasonable initial cost.

(7) Owing to its simple chemical composition—consisting of two forms of amorphous silica of similar characteristics—it should be more easily susceptible of reuse than mixtures of complicated composition.

Aluminum-Alloy Permanent-Mold Castings

By Dr. Robert J. Anderson,* Cleveland, Ohio

Introduction

In the United States, aluminum-alloy castings are produced commercially by three main processes, viz., the sand, die, and permanent-mold methods. The properties and qualities, and hence the fields of application, of the castings produced by these three processes are markedly different, as will be readily seen when the inherent characteristics of the methods are considered. In the aluminum-alloy field, the permanent-mold process has advanced from a small scale semi-commercial method to a successful quantity production process in a comparatively short period of time.

A permanent-mold casting is defined as a semi-finished (or it may be practically finished) casting made by pouring a liquid alloy into a metal (usually cast-iron) mold, the alloy entering the mold under the force of gravity solely. Steel or cast-iron cores are generally understood to be used in permanent-mold casting. Aluminum-alloy castings are also produced in cast-iron molds but using sand cores. Other processes which have been used for making aluminum-alloy castings involving metal molds include the Cothias method, slush casting, and centrifugal casting, while the semi-permanent mold process, in which molds are made of baked refractory materials, has received some attention. Certain of these processes have been used to some extent abroad but only slightly in the United States.

The recent advances that have been made both here and abroad in the application of the permanent-mold process for the production of castings of increasing weight and complexity have been noteworthy and have attracted interest on the part of sand founders and die-casting producers. The permanent-mold process has become a direct competitor of sand founding and die casting

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for the production of certain types of castings. One object of the present paper is to indicate to foundrymen the directions which have been taken by the more recent developments and to present such information, and to indicate where additional information can be found, as will assist them in taking up the production of castings by the permanent-mold process. The demand for aluminum-alloy permanent-mold castings is growing rapidly, and both the sand founders and die-casting companies may profitably look into this method as a rapid and economical production process for certain types of castings. The writer will venture to predict that in the near future a permanent-mold-casting department will be a necessary adjunct in the majority of aluminum-alloy sand foundries and die-casting plants.

Another object of this paper is to discuss briefly the properties, mode of manufacture, and fields of application of aluminum-alloy permanent-mold castings and to give comparison with sand castings and die castings, thus assisting the consumer of castings in making a judicious choice of the correct kind of casting for specific purposes. Since the properties and qualities of parts made by the three main casting methods are markedly different, the purchaser of castings is no more justified in simply ordering aluminum-alloy parts without proper consideration of the specific method by which the castings should be made than he would be in ordering ferrous castings without specification as to whether they should be malleable, gray iron, or steel.

The history of development of the permanent-mold process and the basic principles involved in the method have been discussed by the writer[1] and M. E. Boyd in another place, and general treatment of the subject is given in the writer's book[2] on the metallurgy of aluminum. A general discussion of the subject, especially as regards aluminum-alloy castings, is also given in a recent series of articles by the writer.[3]

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[1] R. J. Anderson and M. E. Boyd, The production of castings in permanent molds, paper before the Inst. of British Foundrymen, Newcastle-on-Tyne meeting, June 1924 (American exchange paper).

[2] R. J. Anderson, The metallurgy of aluminum and aluminum alloys, Henry Carey Baird and Co., Inc., New York, 1925; see pp. 613-634.

[3] R. J. Anderson, Aluminum-alloy permanent-mold castings, The Foundry Trade Jour., vol 33, 1926, pp. 93-94; 105-108; 125-128; 173-174; 237; 255-256.

Permanent-Mold, Sand and Die-Casting Processes Compared

At the outset, in discussing the permanent-mold process for producing aluminum-alloy castings, it is important to differentiate sharply between this method and the die-casting process. In the trade, there is still considerable confusion in the use of terms employed to describe castings produced by different processes involving metal (steel or cast-iron) molds. As stated above, a permanent-mold casting is defined as a casting made by pouring a liquid alloy into a metal mold, the alloy entering the mold under the force of gravity solely. In die casting aluminum alloys the alloy is forced into a die cavity by air pressure. The permanent-mold process is essentially similar to sand casting in that it involves a mold, cores, and pouring by gravity. In England, permanent-mold castings are generally called "die castings." Speaking generally, the permanent-mold process may be regarded as occupying a position midway between sand casting and die casting, when the light aluminum alloys are considered, and moreover it has a distinct field not covered by either.

Permanent-Mold Process: In the permanent-mold process, the liquid alloy is poured into a previously heated and assembled cast-iron mold, the alloy is allowed to solidify, the core pieces (when used) are taken out, the mold parted, and the casting removed. The mold halves are again brought together, the core pieces inserted, the mold locked, and another pour is made. In production, this procedure is simply repeated over and over again. In designing and building molds, an usual aim is to provide for uniform and progressive freezing of the casting and the feeding of the solidification contraction of the alloy in the casting by gates and risers, thus preventing the occurrence of internal shrinkage cavities. In die casting, the feeding of solidification contraction from gates is impractical. Metal cores are generally used in permanent molds, these cores being made of alloy steel, carbon steel, or cast iron, but usually the first mentioned. Cores may be solid or made up of a number of sections, depending upon circumstances. As mentioned previously, sand cores are also used for some castings instead of steel cores, particularly for parts where the coring is such that multiple-section cores could not be withdrawn.

Considerable progress has been made recently in the United States in using sand cores in cast-iron molds, and this development has gone far in England.

Permanent-mold casting is a quantity production process, and not many parts con be considered for economical production in lots of less than 500. This is so because of the expense of making the

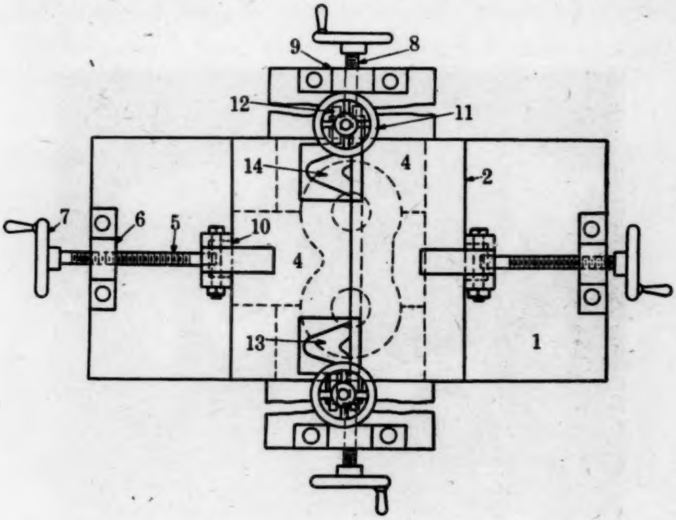

FIG. 1—PLAN OF PERMANENT MOLD; CLOSED (SZÉKELY) .

mold and cores. Mold costs are, however, materially less than die costs in die casting. The rate of production in permanent molds is more rapid than in sand casting, and low-priced operating labor can be used for pouring the castings; hence, permanent-mold castings may be less expensive than sand castings. Various practical details regarding the production of aluminum-alloy castings in permanent molds are described in an able paper by Mortimer[4] and in a paper by the writer[5] and M. E. Boyd, which may be

[4] G. Mortimer, The die casting of aluminum alloys—a review of current methods, paper before the Inst. of Metals, London meeting, March, 1926.

[5] R. J. Anderson and M. E. Boyd, The production of aluminum-alloy pistons in permanent molds, Trans. Amer. Foundrymen's Assoc., vol. 32, part 1, 1925, pp. 226-286.

consulted for further information. Fig. 1 shows the plan of a permanent mold. Fig. 2 shows a small mold and the castings produced thereby. Fig. 3 shows a mold for producing aluminum-alloy pistons. Fig. 4 shows a mold for making dynamo-starter housings, with the cores.

Sand Casting: The bulk of the production of aluminum-alloy castings is made by sand founding. The sand-casting method is applicable to the most varied types of parts as regards size,

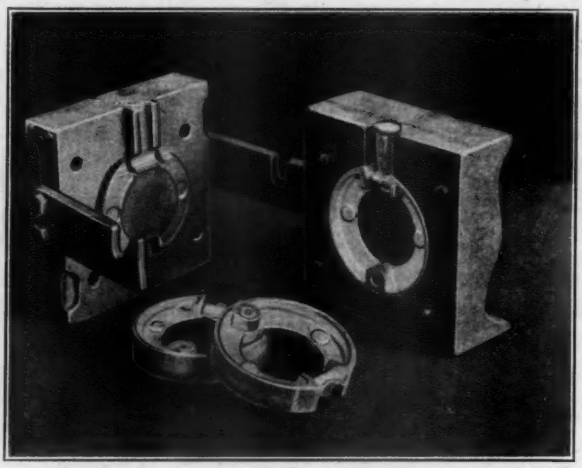

FIG. 2—PERMANENT MOLD AND CASTINGS (MORTIMER, WM. MILLS, LTD., BIRMINGHAM, ENGLAND)

shape, intricate coring, and other features. The production of castings in sand consists in pouring the liquid alloy into a previously prepared sand mold, the alloy assuming the shape of the mold cavity, and retaining that shape (approximately) when frozen. In making the mold, damp sand is rammed into a box or flask using a pattern to give the required contour of the casting. The cores are made of sand, and these are set in the molds as required. Skillful foundry practice, especially in moulding technique, is highly important in sand founding. This is not the case in permanent-mold work where mold operators can be taught

the essentials of the process in a few minutes and can be producing satisfactory castings at fair speed in a few hours. In sand practice, the mold and cores are, of course, destroyed with each pour. A sand casting is normally an unfinished part, and machining is required to put it into condition for use or assembly. The process naturally has a particular field in the production of parts with difficult coring, large castings, and for jobs where only a few castings are required.

Die Casting: A die casting is defined as a finished, or semi-finished, casting made by forcing a liquid alloy into a metal (steel)

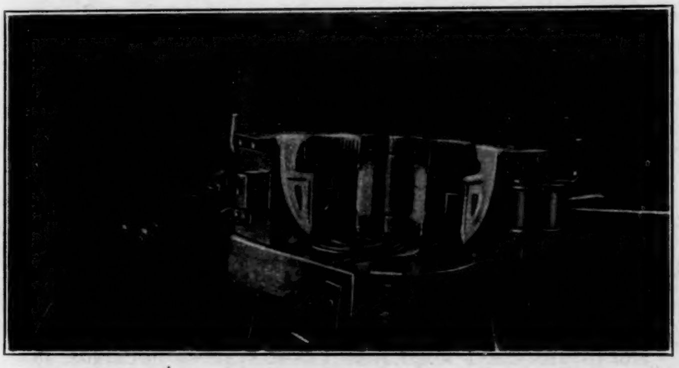

FIG. 3—PERMANENT MOLD FOR PISTONS (KANT-SKORE PISTON CO., CINCINNATI, OHIO)

die cavity by pressure. It is usually pre-supposed that little or no machining will be required on die castings. A permanent-mold casting may be a finished casting as made, after removal of gates and dressing. Emphasis should be laid upon an essential feature in the die-casting process, as applied to aluminum alloys, which sharply distinguishes it from other processes involving metal molds (or dies), viz., the alloy is forced into the cavity by air pressure. Pressures up to 1,500 pounds are used. Mechanical (plunger) pressure has not been practical in die casting aluminum alloys.

A die-casting machine is employed in the process, consisting of suitable mechanism to operate the steel die and its cores, a pot

to hold the liquid alloy, and a gooseneck or nozzle container to transfer the alloy from the pot to the die opening. In operating the machine, the die halves are moved together and the cores brought into place (both mechanically), the die is locked, the nozzle is filled with liquid alloy and then moved into position opposite the entrance sprue of the die cavity, air pressure is applied to the nozzle, and the alloy is forced into the die. The casting is then ejected, and the process repeated. The mode of manufacture of die castings is the cause of their chief disadvantage, viz., internal holes. The surface skin of a die casting is normally sound and smooth, but the interior of the casting con-

FIG. 4—PERMANENT MOLD FOR DYNAMO-STARTER HOUSINGS; DISSEMBLED (GUILLET)

tains numerous holes and shrinkage cavities. When an alloy is forced into a die cavity under high pressure it solidifies almost instantly, and since the entrance gate is usually made thin to minimize swirling effects when the liquid alloy enters the cavity, the sprue also freezes quickly. The casting itself freezes first on the surfaces next to the relatively cold die wall, which is water cooled, and as it freezes the solidification shrinkage is fed, not from gates and risers as in the sand or permanent-mold methods, but from the inner parts of the casting itself, particularly the heavier sections which are still liquid. Hence, the parts which are last liquid show internal shrinkage holes, and practically all air-pressure die castings contain this defect. The entrapping of gas

evolved on solidification and of air in the die may also contribute to porosity. Die casting is essentially a quantity production process, and but few parts can be considered for economical production in lots of less than 1,000. This is necessarily so because of the heavy cost of preparing the dies and the large fixed investment in machines and equipment.

Comparison of Castings Made By the Three Processes

In considering the purchase and use of castings, the consumer is interested in knowing the advantages and disadvantages of parts produced by the different processes, their relative costs, their

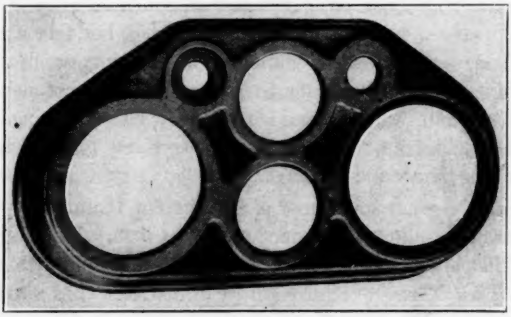

FIG. 5—INSTRUMENT PANEL FOR A MOTOR CAR (KANT-SKORE PISTON CO., CINCINNATI, OHIO)

properties and qualities, and their suitable applications. In a general way, it may be said that taking a given casting which could be made readily by each of the three methods, die castings are least expensive, permanent-mold castings stand next, and sand castings are the most expensive, considering large lots. The sand-casting method is indicated for large castings, complicated small castings, parts which are to be made in small numbers, and general jobbing work.

For simple and small castings and even fairly complicated small to medium-size castings which do not need to be particularly strong or sound, but which are to be made in large numbers, the die-casting method is preferred. This process is well adapted

for producing parts in which great accuracy in dimensions, uniformity of successive castings, and good finish are required. Castings with very thin walls can be made by die casting, with consequent saving in weight of parts. Holes can be cast to close tolerance, and the accuracy of dimensions controlled so as to reduce machining operations to a minimum; in general, however, die castings may require no machining prior to assembly. Die castings can be produced at a much faster rate than permanent-mold castings.

In the case of reasonably simple and small to moderately large castings which are to be made in large numbers and which must be sound and strong or polish well, the permanent-mold process is advisable. The use of permanent-mold castings is indicated generally where a superior product is required, but where a forging is ruled out because of difficulty in forming or because of cost considerations. Permanent-mold castings cannot usually be run with as thin walls as sand castings. These castings polish well and machined or polished surfaces show greater freedom from defects than sand castings.

Relatively great soundness is an inherent feature of properly made aluminum-alloy permanent-mold castings. This is due to the fact that alloys cast in chill molds are more sound than when cast in sand. X-ray examination by the writer[6] has shown that aluminum-alloy permanent-mold castings are normally uniformly sound throughout, as contrasted with die castings which contain large holes beneath the sound surface and sand castings which generally exhibit a more or less porous condition. Permanent-mold castings may contain isolated blowholes as well as minute porosity, but such defects are traceable to incorrect gating or other factors which can be controlled. At the same time, such defects do occur in commercial castings. Soundness in castings is, of course, desirable in order to avoid the use of larger sections to compensate for porosity. The well-known pinholing defect which is usually associated with sand castings is ascribable to the escape of dissolved gas on solidification and the fact that the relatively slow solidification which occurs in a sand mold

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[6] R. J. Anderson, X-ray examination of aluminum-alloy castings for internal defects, Transactions Amer. Foundrymen's Association, vol. 33, 1926; pp. 261-279.

favors the occurrence of this defect. Experience and various experiments, e. g., those of Archbutt,[7] have shown that if solidification is sufficiently rapid, as in a chill mold, the dissolved gases in aluminum alloys are not liberated but instead are retained in solution in the frozen alloy. On the other hand, if solidification is very slow, as on cooling a melt in the furnace, the gas is liberated and escapes from the melt. At some intermediate rate of freezing, as in a sand mold, the gases are liberated from solution but become entrapped in the solidifying alloy in the form of minute bubbles giving rise to porosity (the pinholing defect). Polished macrosections clearly show the relative soundness of permanent-mold and sand castings.

It is generally feasible to avoid internal draws in permanent-mold castings by proper design of molds and gating so that the casting is adequately fed in contradistinction to air-pressure die castings which cannot be fed and which are normally certain to contain many holes and shrinkage cavities. The grain size of permanent-mold castings is smaller than that of corresponding sand castings due to the more rapid rate of solidification of the former.

The mechanical properties of aluminum-alloy permanent-mold castings are much better than those of corresponding sand castings owing to the fine-grained structure and better soundness of the former. Thus, the tensile strength of permanent-mold castings in most aluminum alloys is usually 25 per cent greater than that of sand castings, while the elongation may be twice as much and the hardness markedly higher. The mechanical properties of die castings are variable and unreliable due to the holes and shrinkage cavities which are always present. Owing to the uniform and superior mechanical properties of permanent-mold cast alloys, parts previously made in sand may often be designed for permanent-mold production with resultant economy in weight and cost. Permanent-mold castings are more accurate in dimensions than sand castings, but are not normally so accurate as die castings. However, they are usually sufficiently accurate as to size tolerances to save machine work on all dimensions, and the

[7] S. L. Archbutt, A method of improving the properties of aluminum-alloy castings, Jour. Inst. of Metals, vol. 34, 1925, pp. 227-239; and Aeron. Res. Comm. Repts. and Mem. No. 959, H. M. Stationery Office, London, 1925, 11 pp.

uniformity of size assures close fits to jigs and fixtures which may be required in machining for assembly. It is presumed that little or no machining will be required to put a die casting into condition for use, although at times the accuracy of die castings is not sufficiently great to permit their use without machining. When machining is required on a die casting, such castings lose their main advantage.

To sum up: Permanent-mold castings rank first in mechanical properties, due to their fine grain size and relative soundness. They have greater strength and hardness, higher elongation, greater resistance to impact and alternating-fatigue stresses, and greater resistance to corrosion than sand castings. Owing to their original relatively uniform and good mechanical properties, permanent-mold castings are highly advantageous for parts to be heat treated, and the enhancement of properties on heat treatment is greater than with sand castings. Die castings are inherently unsuitable for heat treatment, due to the large holes and cavities which they contain; moreover, on heating such castings the air or gas contained in such holes is forced to the surface, causing blistering. Since permanent-mold castings rank first in soundness, they are well suited for leak-proof parts and for cooking utensils and enameled parts where it is desired to avoid blistering on exposure to heat. Permanent-mold castings machine well and yield less machining scrap than do sand castings. The machining allowance required for permanent-mold castings is substantially less than for sand castings, due to their greater accuracy and uniformity in size of successive pieces.

Uses and Fields of Application

In the aluminum-alloy field, the merit of the permanent-mold casting process has not been given sufficient consideration by sand foundrymen in general, nor has the product been generally brought to the attention of the great field of possible consumers. The permanent-mold process is broadening the market for light aluminum-alloy castings by providing a reliable product which can be made to meet a wide range of required mechanical properties. Permanent-mold castings are now being used for

purposes where sand castings had previously been considered out of the question for various reasons. At the present time, the process is a direct competitor of sand and die casting in the production of aluminum-alloy parts for several important industries. Large numbers of parts are now being regularly made in quantity production and the applications to date have been numerous. The process should make a direct appeal to sand foundrymen for the production of certain of their castings now being made in sand, as well as to die casting manufacturers.

Broadly speaking the field of application of the permanent-mold process is for any casting which is not too large, too intricate in shape, or having too thin walls, and where strength and soundness are primarily essential. Subject to these qualifications, the process applies to any casting where special metallurgical specifications are to be met, where polishing is to be done, and particularly where heat treatment is required. In passing, it should be stated that permanent-mold castings are in competition with forgings where a superior product is required but where the cost of producing a forging, due to difficulty in making the shape or lack of sufficient number of pieces, does not warrant its use.

The greater part of the aluminum-alloy permanent-mold casting production has been used in the automotive industry, but there has been a definite expansion in the specification of these castings by other major industries and the general engineering trades. A consideration of the properties and qualities of aluminum-alloy permanent-mold castings will suggest to engineers the possible field of application. The following gives a partial list of the present uses of such castings: Automotive parts, various; bearing caps; bearings; brackets; brake shoes; brake support plates; calculating-machine parts; camshaft bearings; cooking utensils; covers; cream-separator parts; dish-washer parts; distributors; drinking-fountain bowls; electric-drill parts; electric-fan parts; electrical-apparatus parts, various; farm-lighting equipment; fishing-tackle pieces; fittings, various; gasoline caps; gasoline-pump valves; gears, straight and bevel; glass clips; handles, door and other; hardware, automotive and small; household appliances; housings, gear and various; instrument panels, motor car; knife handles; motion-picture projector parts; motor-cycle crankcases;

motor-cycle parts, various; motor heads; motor parts, small; novelties, various; oil gages; outboard-motor brackets and other parts; percolator parts (bases, valves and spouts); pipe fittings; pistons, internal-combustion engine; plates; radiator caps; radio parts; rotor castings, induction motor; spray guns; steering-column brackets; thumb screws; tool hardware; trim pieces for motor cars; trunnions, light; vacuum-cleaner motor housings;

FIG. 6—PISTON FOR AUTOMOBILE MOTOR, AS CAST (KANT-SKORE PISTON CO., CINÇINNATI, OHIO)

vacuum-cleaner parts; wheels, motor car; windshield parts, automobile; and wing screws.

The accompanying illustrations of Figs. 5 to 8, inclusive, show a few of the various parts now being made in permanent molds. The confines of space prevent including additional illustrations, but the list given above has indicated the variety of parts being produced. Fig. 5 shows an instrument panel for a motor car. Fig. 6 shows a standard motor piston as cast. In passing, it is of interest to point out that, prior to a few years

ago, the permanent-mold process as applied to aluminum alloys was used largely for the production of pistons, and the success of the method in this field gave impetus to the use of the process for other castings. Tests have shown that the permanent-mold cast piston is superior to the sand-cast product and also to the product made by casting in permanent molds using sand cores. Sand-cast pistons pit more easily than the permanent-mold cast, due to greater porosity. Dynamometer tests by prominent motor-car manufacturers in the United States have shown that

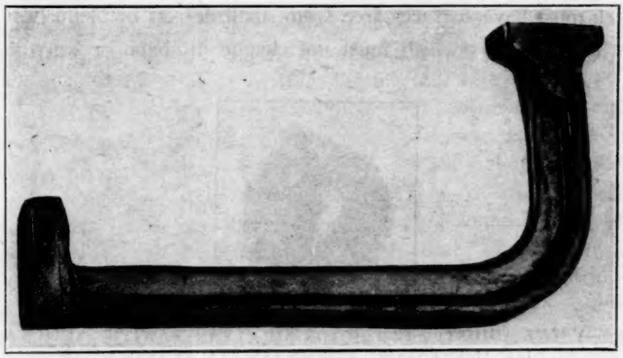

FIG. 7—BRACKET FOR RADIO OUTFIT (KANT-SKORE PISTON CO., CINCINNATI, OHIO)

pistons made in permanent molds with sand cores are inferior to those made with steel cores. Fig. 7 shows a small bracket for a radio outfit, and Fig. 8 shows a small valve adjuster for a motor air cleaner with teeth cast to size. The castings shown in Figs. 5 to 8, inclusive, were poured in different aluminum alloys.

In a general way, it may be said that there are various types and specific kinds of castings which should be made specifically by the permanent-mold process in preference to sand founding or die casting. These include the following:

(1) Various castings made in sand or dies which are not too complicated as to coring and which must be strong and sound.

(2) Any casting of moderate size having a wall thickness greater than ⅛ inch and with straight coring.

(3) Any casting, the proper functioning of which is responsible for human life or the continued operation of machinery.

(4) Any casting which must be leak proof to hold fluids.

(5) Castings which, although made by air-pressure die casting, must be machined to finish.

(6) Castings which are given very close inspection during and after machine operations.

(7) Castings which are to be finished by final polishing and which must have surfaces free from small defects or blemishes.

(8) Castings which must not change in shape or warp and

FIG. 8—VALVE ADJUSTER FOR MOTOR AIR CLEANER, WITH TEETH CAST TO SIZE (KANT-SKORE PISTON CO., CINCINNATI, OHIO)

move at the ordinary temperature on aging (should preferably be made in permanent molds rather than by die casting).

(9) Castings which are to be heat treated.

The application of the permanent-mold process to the above types of castings is, of course, subservient to the qualifications that it is restricted at the present time to parts which are not too large, too intricate in shape and coring, having too thin walls, and to relatively large numbers of a given kind of castings. The permanent-mold process is not advocated by the writer for the manufacture of many types of castings now made preferably by sand or die casting. However, it does have a definite field, and various parts now made by the other casting methods could be produced more cheaply or better by the permanent-mold process.

In choosing a method of manufacture for various types of castings, each case should be decided on its merits, taking into account all factors involved. Certain castings, e. g., bearing caps and similar chunky parts, can be made more economically by the permanent-mold process than by any other method.

Kinds of Alloys Used, and Properties

Any commercial aluminum alloy *can* be cast in permanent molds, but it is not always feasible to attempt to put certain alloys into production. The regular run of alloys now being used in sand-foundry practice and in die castings are being poured in permanent molds, but special alloys have been developed for permanent-mold work. Given no specifications as regards alloy composition for a given casting, the alloy to be chosen from the point of view of the permanent-mold founder depends primarily upon its casting qualities, the nature of the casting, and the particular properties desired. In general, the alloy should have good casting qualities, since an alloy which gives difficulty in operation at the molds may be uneconomical as a foundry proposition. Casting behavior is a quality not easily defined in a precise manner. Lacking the required technical data to define casting behavior, it is something that is determined by men experienced in the production of cast parts. Essentially, it means that the alloy should flow freely at the proper casting temperature, have low contraction on freezing (as well as low liquid and solid contraction) in order to minimize cracks and shrinks, cast soundly with freedom from blowholes and porosity, give clean castings (i. e., free from hard spots and inclusions), and not stick to the mold walls and cores. In practice, it is known that certain alloys cast with a lower percentage of wasters than others.

The chief difficulty in obtaining good castings with low waster loss in the permanent-mold process, when using aluminum alloys, is due to the high liquid and solidification contraction of these alloys in general and their high thermal expansion in the solid state. Low strength (and resistance to impact) at elevated temperatures is also an important factor in adding to the difficulties of the process. The factors affecting the casting behavior of

aluminum alloys in permanent molds have been discussed by the writer [8, 9] in previously published papers.

Of specific alloys used for permanent-mold casting in the United States, the following may be mentioned: 95: 5, 92: 8, 90: 10, and 88: 12 aluminum-copper; 95 : 5, 90: 10, and 87: 13 aluminum-silicon; 90: 4: 6, 92: 3: 5, and 94: 4: 2 aluminum-copper-silicon, as well as other aluminum-copper-silicon alloys; 94: 5: 1 and 92: 6: 2 aluminum-copper-nickel; 90: 4: 4: 2, 92: 4: 2: 2, and 94: 4: 1: 1 aluminum-copper-nickel-silicon; Y alloy (92.5: 4: 1.5: 2 aluminum-copper-magnesium-nickel); various piston alloys, e. g., 89.7: 10: 0.3, aluminum-copper-magnesium; 92: 1: 5: 2 aluminum-iron-silicon-tin; and various other alloys. The compositions just indicated are nominal, and the usual commercial variations naturally apply. For castings which are to be polished, various nickel-bearing alloys are preferred, since the addition of nickel to aluminum alloys give a better surface finish and brighter polish which retains its luster well. Certain silicon-bearing alloys are used where considerable elongation is desired, and the aluminum-silicon and aluminum-copper-silicon alloys are of value for general castings.

The tensile strength of permanent-mold cast bars (0.505-inch test bar, unmachined) varies from about 18,000 to 32,000 pounds per square inch as freshly cast, with elongation in the range 0.5 to 10 per cent, and brinell hardness in the range of 40 to 120, depending upon the composition. Heat-treated alloys have properties in the following ranges: tensile strength, 24,000 to 55,000 pounds per square inch; elongation, 0.5 to 8 per cent; and brinell hardness, 70 to 160. Thus, a very wide range of mechanical properties is obtainable to suit a variety of requirements. The tensile properties of permanent-mold cast aluminum alloys are very markedly affected by the shape of the test bar, method of gating, speed of pouring, number of bars cast together in a mold, temperature of mold, and pouring temperature of alloy. Tensile bars with sharp fillets are badly stressed. A flat bar with long conical fillets appears to give the most uniform results.

[8] R. J. Anderson, Aluminum-alloy permanent-mold castings, The Foundry Trade Jour., vol. 33, 1926, pp. 93-94; 105-108; 125-128; 173-174; 237; 255-256 (see p. 173).
[9] R. J. Anderson, Aluminum alloys for piston castings must meet varied requirements, Autom. Ind., vol. 53, 1925, pp. 1030-1034

The mechanical properties of two alloys as chill cast and sand cast are as follows: 90:10 aluminum-copper-alloy, chill cast; tensile strength, 26,000 pounds per square inch (sand cast, 20,000 pounds); elongation, 2 per cent (sand cast, 1 per cent); and brinell hardness, 80 (sand cast, 70), under 500 kg., 10 mm., 30 secs.; 95:5 aluminum-silicon alloy, chill test; tensile strength, 22,000 pounds per square inch (sand cast, 19,000 pounds); elongation, 6 per cent (sand cast, 4 per cent); and brinell hardness, 43 (sand cast, 40).

Sizes, Weights and Casting Tolerances

Aluminum-alloy permanent-mold castings are made in sizes from say one inch long (or in largest dimension) up to about 15 inches or more long. Larger castings, like crankcases, are cast abroad using sand cores. Most of the permanent-mold casting production in the past has been confined to parts weighing less than 2 pounds, but with recent developments, a number of parts are being run with weight varying from 5 to 15 pounds. The minimum weight of castings produced is about ⅓ ounce and the maximum 25 pounds; crankcases weighing 100 pounds have been made with sand cores. In using steel cores, at the present time, the heavier castings should not present too great complexity of design, but with the developments being made in mechanically operated molds, mechanical removal of cores, mechanical ejection of castings, and special heating or cooling devices for molds, there seems to be no reason why heavier casting cannot be produced.

It might be thought that very small parts, e. g., those weighing ½ to 1 ounce, could not be made in permanent molds in competition with die castings. This is, however, possible where the number of parts required does not warrant the expense of making a die, but would warrant making a permanent mold, and also where the mechanical properties are of importance.

The question of size tolerances for permanent-mold castings is one with many controversial aspects. In comparing the accuracy of die, permanent-mold and sand castings, it is usual to say that the size tolerances of die castings are given in thousandths of an inch, those of permanent-mold castings in hun-

dredths and sixty-fourths or thirty-seconds of an inch, and those of sand castings in eighths and sixteenths of an inch. The size tolerance that can be guaranteed commercially depends upon the size and shape of a given casting, the design of mold and method of gating required in its manufacture, and the alloy to be used. The writer believes that it is a mistake to insist that the permanent-mold process at the present stage of development ensures precision castings, and believes in general that it is preferable to talk about limits in sixty-fourths of an inch rather than in thousandths of an inch, as is the case with die castings. Weight tolerances vary, depending upon the size, shape and weight of the castings, but the usual limit feasible in commercial work is ± 1 to 2 per cent. The usual machining allowance for permanent-mold castings is 1/32 to 1/16 inch, but this depends upon conditions.

Manufacture, Design, and Gating

The usual permanent mold for aluminum-alloy work is made of cast iron, and the cores may be cast iron, carbon steel, or special alloy steels. The latter are commonly employed when cores are made up of sections. Molds are parted in two halves, and the cavity is machined partly in each half or entirely in one half, depending upon the casting and other factors. The cores are machined to size and shape so as to give the desired contour to the inside of the casting and provide the required wall thickness. Details of molds have been described by the writer and M. E. Boyd in the papers already cited. Molds may be operated entirely by hand, i. e., opened and closed, or they may be semi-automatic, the opening and closing being done by mechanical means. Multiple core sections are usually set by hand, and the pouring is done by hand. Mechanical operation of molds increases production markedly. Molds may be heated with burners or in an oven until they attain the proper temperature, and the temperature of operation is considerably dependent upon the rate of production. There is great need for definite temperature control of molds, since many wasters are due to variation in this factor. Efforts have been made to apply electrical heating to insulated molds as well as water and oil cooling.

Correct design is an important factor in the successful production of permanent-mold castings, since design is closely related to the method of gating, the type of mold to be used, and the quality of the resultant castings. Impractical casting designs may preclude the use of permanent-mold castings, since some designs are not feasible to cast in permanent molds. The more impractical the design, the greater the cost of producing the casting, and the worse the casting will be from the point of view of its mechanical properties and freedom from foundry defects. At the present time, difficulty is had by permanent-mold castings manufacturers in handling castings which were especially designed for production in sand or by die casting. For economical production and in order to secure the best qualities in a casting, parts should be designed especially for casting by the permanent-mold process. The writer has seen many designs of castings which would make excellent permanent-mold production jobs if altered slightly from their original form, but which, as designed, were practically impossible to make by permanent molding. Design bears an intimate relation to wasters and the occurrence of defects, as will be shown more fully in the following section of the paper.

As mentioned previously, the aim in designing molds is to secure a method of gating which will give a progressive freezing of the liquid alloy, i. e., so that the gates freeze last and hence feed up the solidification contraction of the casting, thereby preventing the occurrence of internal shrinkage cavities, surface shrinks, and other defects. In sand founding, the casting may often be gated at any special places desired in order to take care of contraction and ensure proper feeding. In permanent-mold work, the gate must be placed in the parting line of the mold. Risers can be used freely in sand work to feed heavy sections, but in many cases a riser cannot be used in a permanent mold, although the need exists. Cracking can often be prevented in sand practice and cooling rates equalized by the use of chills, but chills have not worked well in permanent molds. In sand work, cracking due to too hard cores can often be eliminated by using softer cores, but in permanent molds the cores are steel and entirely unyielding.

Internal flanges and undercuts cause the permanent-mold

designer much trouble because the required coring becomes more complicated. Thus, taking an ordinary piston casting, this might be made with a three-piece collapsible core; if an internal flange is present at the bottom of the skirt, a five-piece core is necessary. Some castings require seven-piece cores, where with small alteration in the design a five-piece core could be used. Permanent-molds must be correctly vented, since otherwise certain sections may not fill properly. Venting in sand work is easily taken care of by using an open sand or employing the vent wire to produce gas exit holes at particular places. Venting can be readily done on the parting faces of permanent molds, but in other places air-exit holes must be drilled through, and in many cases it is difficult to decide how best to place such holes. Moreover, such vent holes must be kept open or they are useless, and this often slows down the operation of a mold. Permanent-mold castings are often gated with the longest dimension in a vertical position, the parting line being in the middle of the casting, but other methods are used. In some cases, after a mold is made, the casting will run satisfactorily only if the mold is tilted at some angle with the horizontal. In sand practice, the natural way to mold flat work is with the long dimension in a horizontal position, but in permanent molds this dimension may better be vertical.

Each particular casting, when made in permanent molds, is more or less an experimental proposition until gating and design are correctly worked out and correlated. The aim is to use as simple a gate as possible, and in order to minimize the amount of scrap produced in the form of gates and feeders, these parts are made as small as possible and consistent with the production of sound castings. Even and uniform flow of alloy into the mold is one of the prime requisites of a good gate. This is desirable in order to overcome inequalities in pouring rates which are due to the personal element and cannot otherwise be controlled. Tendencies in gating have changed somewhat since the question was discussed a couple of years ago by the writer[10, 11] and M. E.

[10] R. J. Anderson and M. E. Boyd, The production of castings in permanent molds, paper before the Inst. of British Foundrymen, Newcastle-on-Tyne meeting, June, 1924 (American exchange paper).

[11] R. J. Anderson and M. E. Boyd, The production of aluminum-alloy pistons in permanent molds, Trans. Amer. Foundrymen's Assoc., vol. 32, part 1, 1925, pp. 226-286.

Boyd. At the present time, top gates are being used to a considerable extent, and these give satisfactory results for certain types of castings. On other types of castings, the tendency is to gate directly at the juncture of the side and bottom, using no cross feeders or risers. Some manufacturers use a high riser situated on the line of the main gate and between the point of ingress of the alloy at the gate mouth and the body of the casting. Others have dispensed with risers wherever possible, aiming to

FIG. 9—FRONT VIEW OF INSTRUMENT PANEL SHOWN IN FIG. 5, WITH GATES ATTACHED (KANT-SKORE PISTON CO., CINCINNATI, OHIO)

feed from a single heavy gate and regulate the flow of alloy into sections of different thicknesses by venting. This latter method prevents great advantages in reducing the amount of scrap owing to risers and feeders, but involves difficulties in the proper placing of vents. Two different gating methods are illustrated in Figs. 2 and 3. Fig. 9 shows a view of a method used in gating the instrument panel illustrated in Fig. 5, while Fig. 10 shows a simple method used in gating the bracket of Fig. 7.

Some gates which have given excellent results seem generally wrong from the point of view of filling the mold, and there is still much to be learned about the fundamental principles of gating. In any case, a gate which may give good results on one casting may not give good flow of alloy in another, and in some cases will even prevent proper filling. The position of attachment

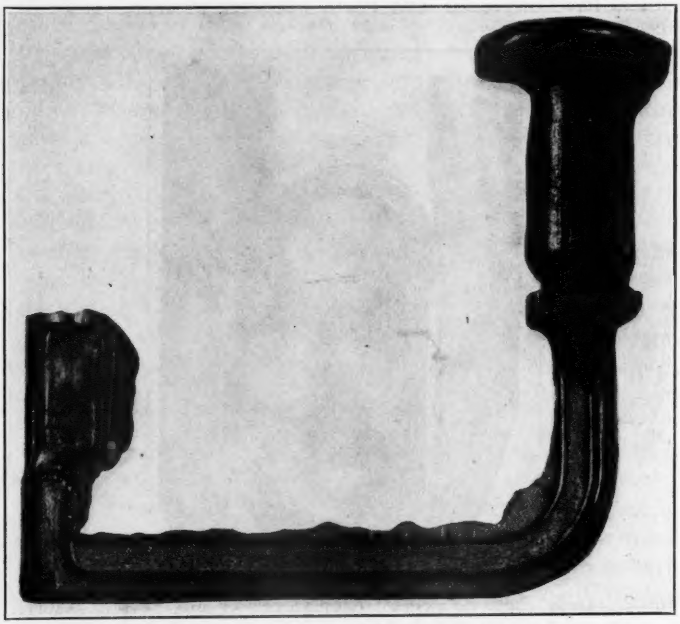

FIG. 10—RADIO BRACKET SHOWN IN FIG. 7 WITH GATES ATTACHED (KANT-SKORE PISTON CO., CINCINNATI, OHIO)

of the gate in the case of castings of regular and simple form may not be important, but with more complicated parts having bosses, webs, flanges and other irregularities the gate may well be placed at a central position with even distribution of such irregularities on either side. In any case, the best method of gating may often not be attained, and some compromise must be made with a gate which will give fairly satisfactory results. The

gating of permanent-mold castings is a question that cannot be discussed in a very definite way, but the problems involved are solved by experience and the method of trial. In some cases, when a mold and method of gating have been improperly designed to give the required results, it is often advisable to discard the mold and start over again rather than to try to patch up the mold and force it to work. The time and labor involved in forcing a mold to work which is improperly designed and gated may cost five times as much as a new mold.

Wasters in Permanent-Mold Casting

The question of wasters incurred in permanent-mold castings production is one of much technical and economic importance, and a thorough study of the nature of the defects incurred under given conditions will go a long way in improving mold-design technique and reducing the cost of output. In the case of the aluminum alloys, there are four factors which have important bearing on the occurrence of defects, viz., (1) the low density of the alloys, which tends to give reluctant filling of molds and inaccuracy of size; (2) the high liquid and solidification contraction, which result in cracks, internal and external draws and shrinkage cavities, and inaccuracy of definition; (3) the high coefficient of thermal expansion (in the solid state), which gives cracks and warped or stressed castings; and (4) the lack of strength at elevated temperatures, which also gives cracks and warped castings. With the recognition of these items in relation to the general subject of wasters, the most important factors governing losses in production of particular castings include the following: (1) design of the casting; (2) composition of the alloy used; (3) tolerances permitted in the castings; (4) melting and pouring temperatures; (5) mold and core temperatures, and variation in temperatures in different parts of the mold; (6) method of gating, and mechanical variations in the mold; (7) method of coring; (8) draft in the mold and cores; (9) venting; (10) speed of pouring; and (11) operating irregularities.

The question of casting losses and wasters can be discussed only in a general way here, but still sufficiently in detail to indicate the nature of the troubles encountered. The chief defects

occurring in aluminum-alloy permanent-mold castings include the following: cracks, blowholes and porosity, air traps, draws and shrinkage cavities, inclusions and hard spots, rough surfaces, overlaps, metal shots, lack of filling, breaks and tears, warped castings, off-size castings, split seams, localized spongy spots, surface checks, water traps, cold shuts, and some others. The causes for these various defects are discussed briefly below.

Cracks constitute a serious and common defect in permanent-mold castings. They are traceable to the composition of the alloy (alloys with high contraction in volume on freezing tend to crack more readily than those with low contraction), to too high pouring temperature, design of the casting (cracks tend to occur at the juncture of thin and thick sections which are not filleted), to wrong temperature of mold or cores, to hanging in the mold, and certain other factors. In the operation of molds, cores must be extracted at the right interval of time after pouring the casting; if left too long, cracking will ensue, or the casting will stick to the cores, or both; if pulled too soon, the casting may bleed, or at least crack and be damaged owing to its hot shortness at the high temperature. It is very important to extract cores and remove the casting from the mold at the proper time interval after pouring. Hair-line cracks not visible on hot inspection may open up and be readily apparent when the castings are examined cold.

The occurrence of blowholes and porosity in permanent-mold castings is less likely and more infrequent than in sand castings. These defects are traceable to gassing of the alloy and are due directly to too high melting and pouring temperatures. Another important factor is too hot molds, which inhibit rapid cooling and hence may permit the escape of dissolved gas which will be entrapped as minute bubbles and hence give rise to porosity. Localized porosity is also traceable to the gating and to too hot cores (the latter often giving rise to spongy spots). Air traps may be confused with sinks or cold shuts, but the former are due to lack of venting and the entrapping of air by the flow of alloy in the mold; air traps are usually readily eliminated by proper pouring, gating and venting. Draws and shrinkage holes, which may be either internal or external, are directly

traceable to the high solidification contraction of the alloys and lack of suitable gating and feeding. These defects are often difficult to eliminate and may require risers, chills, additional venting, enlargement of gates and feeders, and even redesign of the entire mold. Inclusions and hard spots which normally are revealed on machining are generally traceable to the melting practice, and these defects can be readily eliminated. Rough surfaces may be due to the condition of the mold walls, and this defect may also be associated with unclean molds and cores, metal flash pieces dropping into the molds, minute air and water traps, as well as surface draws. Rough and split seams (at the parting line, or in the case of multiple core sections, at the junctions of such sections) are due to badly made molds or cores or to lack of proper repair of molds or cores. These defects can be readily eliminated.

Overlaps are due to turbulence of the liquid metal in its flow in the mold, and are associated with the method of gating, rate of flow in the mold, pouring and other factors. Shrink pads are useful in equalizing rate of flow in the mold. Overlaps are shown as meeting lines of the liquid allow, as it has joined from different directions or lapped over in its flow. Metal shots and splashing are due to too steep gates or too fast pouring. Lack of filling is traceable to a number of factors, including incorrect gating, cold molds or cores, too low pouring temperature, lack of venting, lack of shrink pads, and too slow rate of pouring. The trouble can generally be readily corrected. Cold shuts may often be found in thin sections of castings during the time when a mold is being conditioned for production. Equalization of flow is important in eliminating cold shuts, and this difficulty may often be corrected by altering the size and shape of feeders and shrink pads to direct liquid alloy to weak and slow-filling portions of a mold.

Breaks and tears are usually due to lack of draft in the mold or cores, rough handling of mold, cores and castings, pulling cores and castings when too hot or too cold, and rocking of the cores and casting on removal. Castings may stick to molds and cores due to composition of the alloy, bad condition of the mold

or cores, and on removal, breaks, cracks and tears occur. Warped and offsize castings are traceable to mold design and gating, allowing the castings to remain in the mold for too long or too short periods of time after pouring, the composition of the alloy, condition of the mold and cores, and other factors which can be controlled. Surface checks in castings are, of course, due to surface checks in the mold walls or core faces, which in turn are caused by thermal fatigue, giving checked and cracked surfaces. Water traps (steam traps) are due to failure to shake off water on cooling cores.

Much of the scrap loss arising in permanent-mold work can be readily eliminated by adequate control of the variables and proper supervision. Keeping molds and cores in good condition will go a long way in reducing losses, and the more skilled the molder the better the results. Gating is, of course, very important. Some gates fill the molds much quicker and better than others. Molds should be properly made as regards quality of workmanship and finish. Pouring rates are important; too fast and hard pouring drives the liquid alloy into the parting lines and causes fins and often sticking in the molds. Wherever possible, sharp corners and angles in molds and cores should be rounded slightly. In any case, when putting a new mold into operation, it should first be conditioned for production and the difficulties worked out before placing the mold in the main shop.

Resumé

The present status of the aluminum-alloy permanent-mold casting industry has been briefly discussed, and the properties, qualities and fields of application of permanent-mold castings described. It has been pointed out that the process should be of interest to sand founders and die-casting manufacturers, and the suggestion has been offered that a permanent-mold department will, in the future, be a necessary adjunct in the majority of aluminum-alloy sand foundries and die-casting plants. Comparison has been made as regards the characteristics of sand, die, and permanent-mold castings, and information presented to assist the consumer of aluminum-alloy castings in making choice of the

proper type of casting for particular purposes. Brief resumé of the paper follows:

1. Comparison has been made of the sand, die, and permanent-mold casting methods for producing aluminum-alloy castings, and the essential characteristics of these processes have been discussed briefly.

2. Comparison has been made of the characteristics of the castings produced by the three processes.

3. Aluminum-alloy permanent-mold castings are characterized by relatively great soundness, fine grain size, greater strength and hardness, greater resistance to impact and alternating-fatigue stresses, and greater resistance to corrosion than sand castings.

4. The present uses and the possible fields of application of permanent-mold castings have been indicated.

5. In general, the field of application of the permanent-mold process is for any casting which is not too large, too intricate in shape, or having too thin walls, and where strength and soundness are primarily essential. Subject to these qualifications, the process applies to any casting where special metallurgical specifications are to be met, where polishing is to be done, and particularly where heat treatment is required.

6. The kinds of alloys used for permanent-mold castings are discussed, and the mechanical properties of such castings in comparison with sand castings are discussed briefly.

7. The sizes and weights of castings being made by the permanent-mold process are indicated, and the question of casting tolerances is taken up.

8. Brief details are given of the permanent-mold process, and references are cited to other papers where additional information can be obtained.

9. The questions of mold design and methods of gating are discussed in a general way.

10. The occurrence of defects in castings produced by the permanent-mold process and methods for eliminating wasters in production are taken up.

Discussion

Sam Tour: Not as the reader of the paper, but otherwise, I was interested in running through the paper before giving it to notice where Mr. Anderson places particular emphasis on the great grain refinement of permanent mold castings, their higher fatigue resistance, and so on, more so than any other type of aluminum alloy castings. I question that very much and I should like to hear the aluminum company representatives give us some real information on whether or not permanent mold castings have higher corrosion resistance, alternating fatigue resistance, than sand castings and die castings, and whether or not they are better in any other mechanical way than sand castings or die castings.

R. S. Archer: That is a large question. I might point out one or two general principles that apply on it. First, I don't think there is any question that the metal which is rapidly solidified as in a chilled mold is superior to metal which is slowly solidified, or there is any question that metal that is perfectly fed is superior to metal which is not perfectly fed as in die castings. This is merely in general. When we come to an actual permanent mold casting it is not quite as simple as it sounds. It would be ideal if we could make aluminum castings in chilled molds without the introduction of undue casting stresses and with perfect feeding, but that is sometimes considerably more difficult than to make sand castings.

I would also question Mr. Anderson's general conclusion that permanent mold castings are as a class better mechanically than sand castings. It the case of a fairly complicated casting, it is perhaps safer to have a casting which is not so highly chilled but which is fed better and which is relatively more free from casting stresses rather than a highly chilled casting which may be difficult to feed and which may be thermally stressed. Or, to put the matter another way, a permanent mold casting would be ideal if we could design and operate the mold in a perfect manner.

As to the specific questions on corrosion resistance and alternating stress, and so on, I think these general principles apply: that if we could make a chilled casting under perfect conditions, a simple test bar, we would find, other things being equal, that its resistance to alternating stress was higher than that of sand casting or die casting. As to corrosion resistance, this property should be better on account of better soundness, that is, greater freedom from pinholes or blowholes from which corrosion might start. In other respects, however, the chilled casting process might work against resistance to corrosion.

During rapid solidification there is ordinarily more local segregation than there is during slow solidification, so I don't believe a general answer on that question is possible.

A Member: Which gives the greater increase in tensile strength, the die casting or permanent mold?

R. S. Archer: The chilling effect of die casting is greater than that of permanent mold casting, and for the metal that actually exists in the cross section, I think the strengthening effect is greater, but we have to realize that very often the soundness is not as great in die casting as it is in permanent mold casting.

Sam Tour: Might I add something to Mr. Archer's reply to that question? Die castings are normally considered to be quite porous, and die castings are quite porous we all admit, but for the normal wall section of a die casting as compared to a permanent mold casting of the same alloy, considering the normal structure of a good die casting which will show sponginess at the center and a normal structure of a permanent mold casting which will not show that sponginess, you will average about three to four thousand pounds per square inch better tensile strength for the die casting than for the permanent mold casting in the one-eighth inch section.

W. C. Coulter: We have a casting proposition that we are making in sand, weighing about four pounds. In casting it from the pot, we have about fifty pounds ordinarily in the pot, and as the cost is one of the factors in the case, I was wondering whether anyone could tell me how many permanent molds one would need to give satisfactory results. That is, you get, ordinarily, about ten or twelve castings out of a pot. You couldn't handle it from one mold, I presume. You can't waste much time in handling your mold or your pot will get cold. I was wondering if two or three molds would be required, or could it be handled on one mold before the aluminum got too cold.

Sam Tour: Perhaps you are not acquainted with how a permanent mold pot will run. You will have a pot full of molten metal ready and hand ladled, just sufficient metal to fill the mold at one time. Then your pot will be kept hot all day long and the number of castings you can make will depend upon the size of casting and the rate at which you can operate that mold. You might be able to make about twenty castings an hour, of the four pound castings. It would then be necessary to melt that much metal in a pot per hour, only ladling as much as you need for casting.

Sand Control in the Foundry

By H. W. Dietert* and H. W. Wakefield, Jr.,*
Detroit, Mich.

The control of sand in the foundries of the United States Radiator Corporation has played a very important part in controlling the foundry loss and casting finish. An additional item which must be recognized is that it has enabled the foundrymen to study sand in detail, which gives them a definite working knowledge of molding sands. This knowledge given by sand control is the practical value of sand testing. This part that sand testing plays, while essential, is indirect. The direct benefit is application; knowing the sand requirements and how to get them.

The object of this paper is to describe the improvements in sand control machines and the developments incorporated in sand control test practices of this corporation since the previous paper[1], by one of the authors was presented a year ago. These changes have not been made due to failure of methods previously used, but due to our desire to further simplify sand control.

Daily Tests

The properties of molding sand which may vary sufficiently in one day to cause loss should be determined daily. With this in view, the temper, permeability and strength of the heap and facing sand is tested daily. In this manner, the correct amount of water and new bonding material may be determined each day, thus avoiding loss due to wet or dry sand, weak sand, strong or tight sand.

Temper

The control of molding sand temper may be divided into two parts, namely, the metering of the water added and the checking of moisture by means of a moisture test. A moisture test determining percentage of moisture or temper is not entirely satisfactory for controlling temper of molding sand. A moisture

*Engineering Dept., United States Radiator Corp.

[1] Dietert, H. W., and Myler, W. M., *Molding Sand Control in the Foundry*, Trans. A. F. A., vol. 33, 1926, pp. 721-757.

test will give information only as to whether the sand is tempered correctly. It does not enable the tempering crew to place a definite amount of water on the sand. A water meter with moisture test is essential for complete control of sand tempering.

In Fig. 1 is shown a water meter coupled to a wetting down hose. The meter is mounted on a truck in order that it may be readily moved to the various water stations located in the foundry. The water meter has a vertical dial reading from 0 to 100 gallons. The indicating hand of the meter may be set back to zero when starting on a new floor.

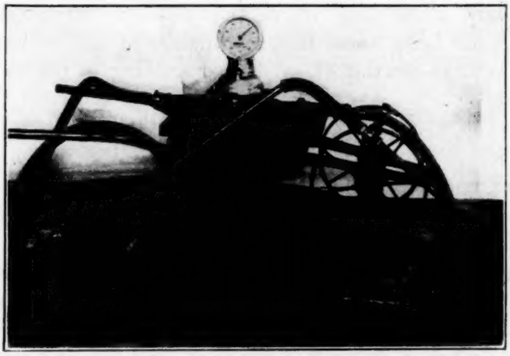

FIG 1—WATER METER WITH WETTING-DOWN HOSE

The procedure in the use of the water meter is as follows: Record the number of gallons of water added to each heap for three or four days under the old system. A comparison of the number of gallons of water placed on each floor with the condition of the resulting sand will definitely show the exact amount of water to place on each floor. Have the sand tempering crew place the number of gallons of water on each floor which produced good tempered sand during the trial run. Record the gallons of water for each floor on the daily control sheet. When the temper of the sand shows a tendency to run to the dry or wet side, change the number of gallons of water accordingly. The moisture loss in molding sand is more constant than commonly

assumed. It is a very simple matter to make adjustment for the seasonal weather changes. Wet and dry days affect only a few inches of surface molding sand exposed to the air.

A floor of molding sand which contains 10 tons of molding sand will require, for example, 140 gallons of water. It would require variations of 24 gallons to give wet or dry sand. By changing the number of gallons to 8 in either direction, one is able to shade the temper of 10 tons of molding sand either to the light or heavy side.

The temper controlled by means of a water meter is much simplified in a shop where pouring, shaking out, and tempering may follow a regular routine. Where the day's production varies, it has been found that the number of gallons required is proportional to amount of sand used and not to the tonnage of iron cast.

Moisture Test and Temper

The moisture test plays an important part in the control of the temper in that it shows the variation in moisture through the heaps from day to day. It also forms a means of checking the temper. In case the moisture reading does not come within the set limit, a correction may be made by the addition of more water or of dry sand. The correction of temper, while very seldom necessary where a water meter is used, certainly is preferable to loss of castings. The moisture indicator attached to the A. F. A. rammer offers a means of obtaining the moisture of molding sand in 20 seconds. The reading of the indicator gives the temper of the sand in a compression number. It may also be calibrated to read in percentage moisture. This indicator is shown in Fig. 6 attached to the permeability rammer.

The percentage of moisture at which heap sand is tempered varies according to fineness, amount of bond and manner of molding. A very common moisture range for medium gray iron molding sand is 6 to 7 per cent. For our plate work 7.5 to 8.5 per cent of moisture is common. If the strength is increased by increase of clay bond or finer grain structure, the moisture required will be greater. The type of molding will influence the percentage of moisture required in that the sand is rammed to

different hardnesses. Sand slinger sand which is rammed hard will usually run best at 5 to 6 per cent; while jolt rammed or hand rammed sand is tempered approximately 6 to 7 per cent.

Permeability

The openness or venting quality of molding sand is best obtained by the use of the A. F. A. permeability apparatus. The permeability numbers obtained by this machine are very important and reliable.

The permeability of molding sand will remain very constant provided the same rebonding sand is used each day and the strength maintained at a definite value. Should sufficient new sand be added to the molding sand to increase the strength of the sand, the permeability will immediately drop. If new sand is left out, the permeability will increase as the strength decreases.

The permeability of molding sand depends upon fineness of the sand grains, amount of clay bond and temper. The fineness of the sand is the controlling element. Each fineness will give a certain venting quality. A base permeability test will give the actual permeability, since the variable clay bond and moisture are eliminated.

The permeability values suitable for various classes of work are not very closely defined in that the combinations found at each foundry are not identical. However, there is a general classification possible which sets the limit at which proper venting and finish are commonly found for a particular type of casting.

Permeability values* known to give good results are as follows:

Light gray iron, hand rammed	20 to 30
Medium gray iron, hand rammed	30 to 40
Radiators cored, hand rammed	30 to 40
Stove plate—Squeeze	8 to 12
Medium plate—Cored or flat squeeze	12 to 20
Flat boiler section, 200 pound to 900 pound jolt	40 to 55
Flat boiler section, 200 pound to 900 pound sandslinger	55 to 70
Round core sections, closed cheeks, jolt stripped	55 to 70

*A. F. A. permeability number.

Strength

The strength of molding sand must be considered in both the green and dry states of the sand. The bond that one feels with the hand is the green strength. The green strength is of importance to avoid difficulty with the sand during the molding and handling operation, and also for its effect on permeability.

Every green sand mold made is a skin dried mold before the mold is completely poured. The green strength on the surface of the mold is destroyed immediately as the iron strikes the sand. The moisture is driven out of the sand by the iron. The sand stands up to its duty due to a dry sand strength. The dry sand strength changes very slowly, while the green sand strength changes quickly. Green strength tests are made daily and the dry sand test is made weekly. The strength of molding sand when completely controlled must be tested in its green and dried state for the green and dry strength.

In order that the green and dry strength of molding sand might be obtained with the least amount of apparatus and test procedure, the compression strength test as previously described[2] was revised. The sand specimen in the revised test is broken by measuring the force required to push one half of the sand specimen off the other half. Or in other words, it measures the ability of the two halves to hang together. The test is illustrated in the latter portion of the paper.

The green sand strength of molding sand will vary as much as 0.2 pounds daily, where normal strength is 1.0 pounds if addition of bonding sand is irregular. This variation is very often accumulated, resulting in a strength around 1.5 pounds which causes poor finish, blows, scabs and dirt loss in hydraulic tested castings; or resulting in a sand with a strength of 0.5 pounds which gives drops and cuts.

Green compression strength values for a few types of molding sand are as follows:

Squeezer plate sand ....1.0 pounds
Sand slinger sand.........................0.8 pounds
Jolt roll over sand flat work..............2.3 pounds

[2] Loc. Cit.

Radiator hand rammed sand..............1.0 pounds
Jolt strip for closed cheeks..............0.6 pounds
Hand rammed floor molding sand medium
work ....1.3 pounds

The quality of new sand required to keep our radiator heap sand up to the desired green sand strength was found to be proportional to amount of core sand spilled into the heap sand. Fig. 2 is a graph showing that where the least amount of core sand is spilled into the heap, the smallest quantity of new sand was required to keep the strength up to the desired value. The consumption of new molding sand may be reduced materially by re-

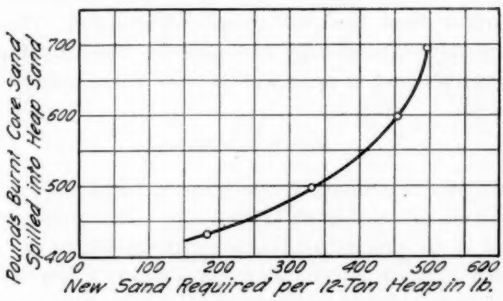

FIG. 2—NEW SAND CONSUMPTION INCREASES WITH INCREASE OF BURNT CORE SAND

ducing the amount of burnt core sand falling into the heap sand. For example, at the plant where only 430 pounds of burnt core sand is spilled on the heap of 12 tons, 180 pounds of new molding sand is required; while 495 pounds of new molding sand is required at a plant where 690 pounds of burnt core sand enters the heap. The reduction of the quantity of core sand spilled on the heap will prove an effective way to reduce consumption of new sand.

Application of Test Figures Temper

The compression moisture indicator may be calibrated to read percentage of moisture. However, it is much simpler to work sand to a certain compression number as determined by means of

indicator. For instance, if compression numbers between 5 and 6 are obtained the day when the sand is tempered the best, then it only remains to have the sand wet down until it compresses between 5 and 6 the next day. Each floor or group of floors will require its particular compression number. A water meter will simplify the adding of the proper amount of water.

Permeability

The permeability values found are the actual volume of air that the sand will pass. Therefore, a sand with 50 permeability is twice as open as a 25 permeability sand. Compare permeability with results secured and the lower limit of permeability or that which gives a dense sand will soon be determined. Permeability may be readily controlled by changing the fineness of the sand. Decreasing the bond in sand will increase permeability.

Green Strength

The strength reading is the number of pounds per square inch the sand is capable of holding up. The green strength is controlled by the amount of bonding clay present in the sand. A high green strength is not favorable towards a low loss. Ram hard and just maintain sufficient green strength to avoid drops. Each type of ramming, as hand, squeezer, jolt and sand slinger requires a different strength. The order of strength is usually in the order named, the sand slinger using lowest strength sand.

Weekly Tests

The importance of dry sand strength was briefly touched in a preceding paragraph. In hydraulic tested castings, one of the easiest ways to reduce scrap is to increase the dry sand strength of the sand which comes in contact with the molten metal, particularly so with sand for the gates and runners, and for any projections or sharp edges. If a sand has a high dry sand strength, it is next to impossible for the molten iron to wash any part of the mold. The bond in a high dry strength sand sets hard when the moisture on the surface of the mold is driven out

by the molten iron, and the mold becomes a skin dried mold. The dry sand strength of molding sand varies from 1 to 25 pounds, depending upon bonding material contained in the sand. The variation found in heap or facing sand is as much as variation found in new sands. This variation in dry sand strength accounts to an astonishing extent for the different loss secured in various foundries.

The green sand strength has always been controlled, for it was possible to feel this strength by hand. However, the dry

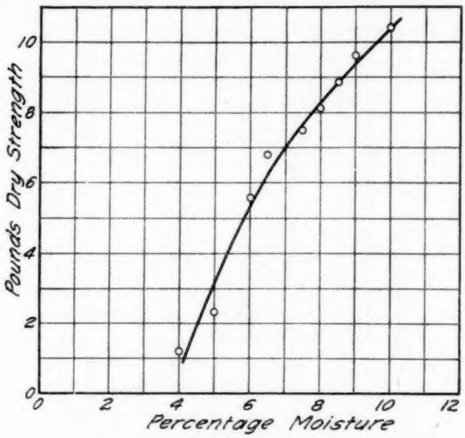

FIG. 3—THE EFFECT OF MOISTURE ON DRY STRENGTH OF MOLDING SAND

sand strength is more hidden and has not been controlled. In conducting a dry sand strength test, the procedure only differs from green strength in that the sand specimen is dried in an oven and then tested.

The dry sand strength of heap sand may be increased by addition of a new sand which possesses a high dry sand strength, by the increase of moisture or by the addition of a binder such as pitch.

Increasing the dry sand strength of heap sand by the addition of a new sand which possesses a high dry sand strength has

been practised for a number of years. The results produced in reduction of loss is quite marked. A sand with a fairly low dry sand strength and a high degree of fineness in grain structure is blended with the high dry sand strength to give the desired finish. A molding sand that set fairly hard when dried from temper state possesses a high dry sand strength.

The relation between dry sand strength and moisture of the Albany heap sand before drying is shown in Fig. 3. The dry sand strength increases rapidly for each increase of moisture. This illustrates very clearly why dry molding sand will cut, wash and drop during pouring, all due to the low dry sand strength. It

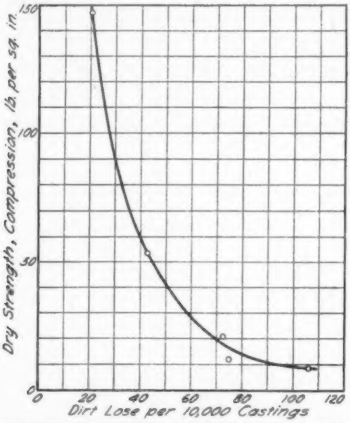

FIG. 4—THE RELATION BETWEEN CASTING LOSS AND DRY STRENGTH OF MOLDING SAND

may be noted that 1 per cent of moisture variation at the temper range (requiring 6 to 7 per cent moisture) of the sand will change the dry sand strength 1.7 pounds. With this in view, the temper of molding sand is of two-fold importance. First, to obtain the desirable green sand properties such as green strength, permeability and texture. Second, to obtain the desired dry strength and dry permeability.

A comparison of the casting loss at the various plants due to dirt on the hydraulic test with the dry strength of the molding sand used shows very definitely the importance of dry strength.

The chart shown in Fig 4 shows the relation between losses due to dirt and dry strength. The plant that used a molding sand

with 7 pounds dry strength ran a dirt loss of 108 castings per 10,000 castings; as against one of the plants running a dry strength of 50 pounds losing only 44 castings per 10,000 castings. The relation between casting loss and dry strength is very definite and should receive the consideration of every foundryman.

The use of pitch binder to increase the dry strength offers a very promising field for further reduction of foundry scrap. The effect of pitch on dry strength is shown in Fig 5. The addition of 3 per cent pitch binder increased the dry strength of the heap sand from 1.7 pounds to 14.8 pounds or approximately nine times.

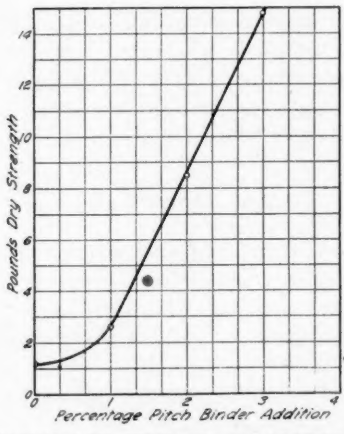

FIG. 5—INCREASING DRY STRENGTH BY ADDITION OF PITCH

Pitch, when added in small quantities to facing sand, or when added direct to heap sand, will greatly reduce loss providing the original sand was low in dry strength. The pitch will also act as a facing, in fact, it is twice as strong as sea coal. When pitch is used with sea coal, reduce sea coal added to one-half and add one-half as much pitch as the weight of the reduced sea coal portion.

An intelligent use of pitch will prove a satisfying means of reducing loss. In one instance, the casting loss on hydraulic tests was reduced 55 per cent by the use of pitch to increase dry sand strength from 1.5 pounds to 5.7 pounds.

Testing Permeability of Molds

Testing the permeability of molds has given us information to help the molders correct their variations in ramming. Appendix 2 is a report of some findings on mold permeability which are considered of interest.

Application of Dry Sand Test Results

The dry sand strength of molding sand shows the setting quality of the sand as the molten iron flows over it. In green sand molding, green strength is useful during the molding period, while dry sand strength is useful during casting period.

The dry sand strength of molding sand for green sand molding may be controlled by the addition of a new sand that contains a clay bond which sets upon drying. In dry sand molding an increase of the usual binders will increase the dry sand strength. These sand binders may be used in green sand molding to increase dry sand strength.

Monthly Tests

The properties of molding sand which are tested at the end of each month are per cent sea-coal, per cent clay, base permeability and fineness. These tests are all a part of the fineness tests as perscribed by the A. F. A., with the exception of the addition of percentage sea-coal and base permeability. These two tests have been added for the purpose of securing additional information.

The sea-coal test as described in appendix 1 is not a very highly perfected test. However, it serves as a means of obtaining the percentage of sea-coal in a sand within an accuracy for practical purposes. The sea-coal test, as developed, is not very suitable for daily tests due to time required. For this reason, a sea-coal determination is made every month in conjunction with the fineness test.

From a purely control standpoint, the information obtained by the monthly tests as mentioned above, while furnishing very instructive data, has not furnished a direct means of reducing foundry loss. This has been due to the fact that fineness or base

permeability is daily controlled by permeability, and percentage clay by strength.

The fineness test, base permeability and percentage of clay are very important, but for heap sand control they may be classed as research tests.

Molding Sand Shipments

Selection.—The determination of how to use the new sand is of equal importance with the quality of the sand. With this in view, one may readily see the folly in the continual change of new molding sand. Choose one or two sands and learn how to work them to get the best results.

In choosing a sand consider first the sand grain structure or fineness, then the clay bond.

The first eliminations may be made on basis of fineness. Discard all sands which do not possess a fineness which will give the desired casting finish. Related to casting finish is permeability. The exceedingly fine sands will be eliminated due to their low permeability. The base permeability should be used for a true comparison of new sands varying in clay bond. Natural permeability will not, as a rule, place the sands in their correct order of permeability due to the great influence of the amount of clay bond that the sands possess, and also due to manner in which a sand was mixed and tempered. After a group of sands have been selected which possess a fineness that will give the desired finish and permeability, one may consider strength next.

For economy, the amount of bond determining the strength of the sand is of prime importance. New sand is added to the heap or facing sand for rebonding. Many new sands are really heap sand when considering the amount of clay bond that they contain. New molding sand consumption may be reduced considerably by the use of a high bonded new sand, or clay bonds. The bonding clays now on the market are closely related to high bonded molding sands. The only practical requirement for successful use is learning how to use them. Heap sand need never be thrown away if a good bonding sand or clay is used. Obtain a bonding material with sufficient clay to keep up the strength and sufficient silica sand grains to keep the heap to size.

Durability of the sand is a factor entering into the economy of the new sand. A rough treatment of the new sand by heating it at 600 degree Fahr. for two hours will indicate how the sand will act in the heap.

The clay bond in a new sand should also be studied as to its setting quality when dried. This quality is the dry sand strength which plays an important part in the casting loss.

The consideration of the sand grains and the clay bond separately resulted in the use of a sand blend which enabled a foundry to run zero loss for four consecutive days and zero loss

Chart 1

SAND SPECIFICATION SHEET ON WHICH ARE TABULATED THE STRENGTH AND PERMEABILITY OF EACH CAR OF SAND

MOLDING SAND CONTRACTS

No. 4 Mills Open Sand

Pch. Order No. .... Pch. of *Rogers Brown.* Plant: *G, D. WN, C, DK*
SPECIFICATIONS: Sand to be tested at *9* per cent moisture. Strength from *10* pounds to *15* pounds. Permeability from *20* volumes to *40* volumes. Sand to be free of strippings and gravel. *99%* to pass *20* mesh; *36% to 44% to be retained on 100 mesh.*

Date Received	Car Initial	Car Number	Strength, Pounds	Permeability	Tested by	Remarks
5-28-26	H.V.	21178	13.0	21.5	S.	O.K.
5-28-26	H.V.	22405	14.8	20.0	S.	O.K.
5-28-26	H.V.	21740	14.0	19.5	S.	O.K.
6- 5-26	H.V.	123543	11.5	19.5	S.	O.K.
6-18-26	P.M.	92390	13.0	21.8	S.	O.K.
6-26-26	H.V.	21873	13.0	21.8	S.	O.K.
7- 2-26	H.V.	21014	13.0	21.8	S.	O.K.
7- 2-26	H.V.	20510	12.7	19.5	S.	O.K.
7- 2-26	H.V.	20907	13.8	20.0	S.	O.K.
7- 2-26	H.V.	120644	11.0	23.4	S.	O.K.
7-23-26	H.V.	21214	17.0	22.0	S.	O.K.
7-23-26	H.V.	21799	15.0	21.8	S.	O.K.

twice in succession frequently. The castings were hydraulic tested boiler sections, weighing 200 to 1000 pounds. The blend consisted of crude silica steel molding sand for perfect grain structure, and a high bonded molding sand of high dry sand strength for the clay bond.

Specifications:—Each car of sand received should be tested. A very satisfactory means of testing the sand is to dry a representative sample. Then wet this sample to a predetermined temper, say 8 per cent moisture. The test sample furnished and samples from each car are tested at temper for permeability and strength. In this manner a quick check is obtained on sand grain structure and clay bond.

Chart 1 reproduces the information on one of our sand specification sheets. On this are tabulated tests of twelve consecutive car lot shipments of an Ohio sand. A comparison of the test figures will show a surprising uniformity of sand shipments.

When considering sand shipments from New York, Ohio, Illinois and Pennsylvania, it has been found that shipper can

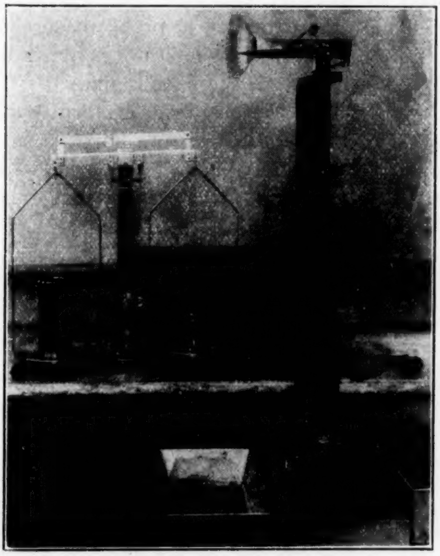

FIG. 6—SPECIMEN RAMMER WITH MOISTURE INDICATOR ATTACHED AND WEIGHING BALANCE

load sand, without undue effort, that will not vary $\pm$ 20 per cent from a specified test figure. This variation in new sand will not cause shop loss where sand control is practised.

Control Core Testing

The core room is a very vital part of a foundry, for the quality of the cores placed in a mold is of equal importance with quality of the green or dry sand used in the mold.

The properties of a core to be controlled are identical with the properties controlled in molding sand. The test methods used vary only slightly from those used in molding sand control.

Moisture:—The moisture added to a core sand mixture greatly influences both the green and dry strength. Water added to a core sand mix produces more green strength than core oil. The dry strength is also increased by an increase of moisture. The percentage of moisture in a core sand mixture may be determined by the A. F. A. oven test, or by the use of the compression moisture indicator. This indicator is illustrated in Fig. 6 shown at G, as attached to the specimen rammer.

The test procedure for moisture determination of core sand mixtures with the compression moisture indicator is identical to that used for molding sand. When the indicator is calibrated to read percentage of moisture for a certain core sand, very accurate results may be obtained. The moisture in percentage or compression figures may be determined in less than 20 seconds. This allows a moisture check to be made before sand leaves the mixer.

Green Strength:—The green strength of core mixture is a very important item for many types of cores. The green strength increases with moisture, fineness, clay substance and binders added. The sand strength machine is used to obtain the green strength of core sand mixtures.

Dry Strength:—The dry strength of cores is usually obtained in either flexure or tensile loading. In order to simplify the control test procedure and reduce number of machines required, the dry strength of cores is obtained from the A. F. A. permeability specimen in a flexure loading. The specimen is rammed in the A. F. A. permeability rammer and is broken in the sand strength machine. In this manner, a very simple specimen is used which is easily rammed and baked on a dry plate without touching specimen by hand while in green state.

Permeability:—The permeability of cores is influenced by the same properties as those which influence molding sand. The test procedure is identical with one exception. The exception being that the core specimen is left in the tube and is baked before permeability reading is taken.

Appendix 1

Determination of Sea Coal in Molding Sand by Kerosene Flotation.

Introduction—Considerable study has been devoted to the development of a practical sea coal determination test. The principle of the test as described in this report was originated by Mr. Stanley Bernadine.

Object—The introduction of a test method whereby the amount of sea coal contained in molding sand may be determined by floating the sea coal in kerosene. It is of a great advantage to know accurately the sea coal content of the molding sand. This is particularly true where the sea coal is placed in the heap sand thus doing away with facing sand. The foundry man can more accurately determine the amount of sea coal to add to the heap providing he knows the percentage of sea coal accumulated in the heap sand.

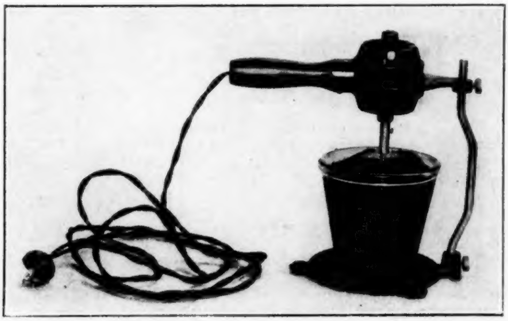

FIG. 7—ELECTRIC MIXER USED IN FINENESS TEST

Apparatus and Materials—Electric Mixer (Fig. 7), Washing Pan (small bread pans) 4x5 inches. Hydrochloric acid, kerosene. Oven. Balance.

Method—Three hundred grams of the dried material being analyzed are weighed into a pan. To this is added 200 c. c. of kerosene. The kerosene-sand mixture is then stirred with electric

mixer for one minute. Next add 20 c. c. of hydrochloric (30-35 per cent HCl.) and 500 c. c. of water. The new mixture is stirred for 4 minutes, with the mixer inclined at such an angle as to throw the sand up into the water. This is best accomplished at an angle of about 60 degrees with the horizontal. More water is then added to bring the level of the kerosene in the pan to within a half inch of the top. The mixture is then allowed to stand for 10 minutes.

Using a shallow scoop, the floating mass of kerosene and sea coal is removed until the black floating material does not cover the surface of the water. The mixture is then stirred again for three minutes and allowed to stand for 10 minutes. Then the floating material is completely removed. In the second stirring it is found best to keep the stem of the stirrer vertical. After removing the floating material for the second time, the pan is allowed to stand for half an hour.

Table 1

Sample	Percentage of Sea Coal Added to Sand	Percentage of Sea Coal Found	Difference in Per Cent
1	0.0	2.4 1.7	2.05
2	13.0	15.2 15.3	2.25
3	16.7	19.1 19.3	2.50
4	20.0	21.3 21.6	1.45

The water is then poured off as completely as possible, without allowing any sand to escape. The sea coal adhering to the sides of the pan is wiped off with a cloth. The mass is then dried at about 250 degrees Fahr. for one half hour. Weigh the dried sand grains, subtract this weight and calculate percentage of sea coal.

Results—Sea Coal and plate sand which did not contain any sea coal were mixed in known percentages. These samples were then tested for sea coal. The results of this test are tabulated in the Table 1.

A study of results tabulated in Table 1 will show that percentage of sea coal by test shows 1.4 to 2.5 per cent higher than actual percentage of sea coal added to the sand. The percentage

of sea coal by test on the heap sand to which no sea coal was added was 1.7 to 2.4 per cent. This may be explained due to dehydration of clay bond and flotation of a small portion of the mobile clay bond.

The amount of mobile clay bond contained in heap sand is undoubtedly very small and quite uniform. Therefore the amount of mobile clay bond and dehydration loss which is included in percentage of sea coal will run exceedingly uniform. For control test use percentage of sea coal as reported to govern the sea coal addition.

The percentage of sea coal found by using the procedure of this test may be termed exact from control standpoint. The values found may be readily checked as shown in Table 2.

Table 2

Sample Sea Coal

5	11.1 11.6 11.9	7	8.8 Jan. 24, 1926 8.9 Jan. 24, 1926
6	7.4 7.8	8	7.4 Feb. 1, 1926 7.3 Feb. 1, 1926

In Table 2 one may note a fair degree of accuracy of duplicating test values on the same sample. In no case were test values of sufficient error to cause incorrect information for control work. On samples 7 and 8 Detroit Col. sand the sea coal percentage dropped from 7.8 to 7.4 per cent. Samples being respective for dates Jan. 24 and Feb. 1, 1926. Between these periods the sea coal added was reduced which agrees with test results.

In order to determine the effect of removing the sea coal on the percentage of clay test the following comparison is of interest. The percentage of clay obtained by the clay test was 11.2 per cent before extracting the sea coal. On the same sand after the sea coal was extracted only 8.3 per cent clay was obtained. This shows a decrease of 3.1 per cent in reading. Three causes may be responsible for this:

1. The dehydration of clay upon drying after sea coal separation, which would prevent the clay being flocculated by the sodium hydroxide.

2. The presence of the unremoved kerosene causes the clay to ball up in contact with water.

3. The A. F. A. clay test removes a small portion of the sea coal. This would make the percentage of clay read high if the sea coal was not removed before the clay test.

Conclusion—1. The test method outlined does not give accurately the sea coal content of a sand. However, it is a method that will be found to be quite practical for a plant control test. It has been demonstrated that there is a very close relation between the sea coal added and the values found.

2. The apparatus designated or similar material should be used, especially as regards the type of stirrer, as less vigorous stirring results either in an incomplete separation or in a great deal of clay being removed.

3. In applying the method described to plant work, it will very probably be found necessary to determine the best value for each kind of sand as the relation between the amount of sea coal and the value found appears to vary with the kind of sand used.

4. The electric stirrer used is recommended to be used in place of shaking the bottles as outlined in the fineness test. A longer stirring stem should be made for the electric mixer, made so that the stirring rod will reach to the bottom of the washing bottle.

5. The sea coal test as outlined here is recommended for the determination of sea coal on monthly fineness sample.

6. Considerable time and study is being devoted to the development of a more refined and simple sea coal test in order that percentage of sea coal in each heap may be determined daily without undue effort.

Appendix 2

Testing Permeability of Molds

Object—A molding sand with a sufficient permeability, or openness, of 40 may be supplied to a molder who may ram the sand into a very hard or soft state, thereby producing conditions of the sand on which the molten iron will not lie or take a correct contour of surface. The permeability of the mold surface may be obtained by means of standard permeability apparatus,

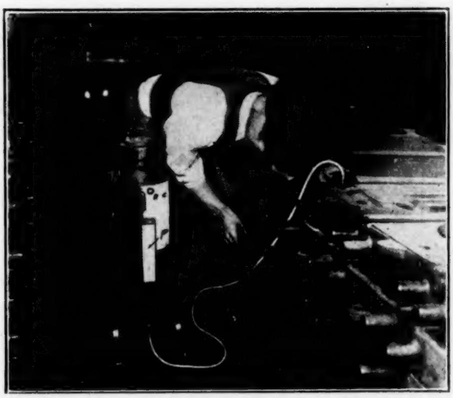

FIG 8—A. F. A. PERMEABILITY MACHINE WITH EXTENSION TUBE BEING USED TO DETERMINE PERMEABILITY OF A MOLD

thus checking the uniformity and degree of ramming by comparison of permeability values.

Apparatus—A. F. A. Permeability Testing Machine (Fig 8) and extension tube.

Method—The permeability of the molds is obtained by attaching to the permeability apparatus a ¼ inch flexible metal tube, as shown in Fig. 8. The rubber tip on the loose end of this hose is cut into a conical shape in order to produce a sharp rubber edge, which allows an air tight joint to be made against the surface of the mold by applying a slight pressure. The permeability of the mold is taken by pressing the rubber tip of the gas hose

against the mold surface, as shown in Fig. 8. The pressure indicated on the pressure gauge "A" is then noted. The next operation is to locate this pressure reading in the table attached to the drum of the permeability apparatus. Just opposite the pressure reading in Column "B" may be found the corresponding permeability number in column "C".

Result—The permeability of the various sections of molds on various floors has been obtained. A sketch of a 38 inch 3

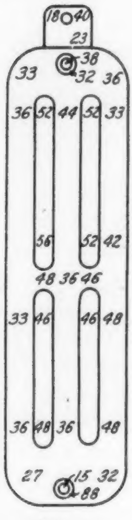

FIG. 9

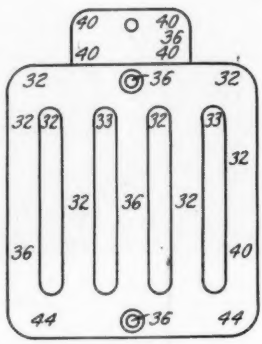

FIG. 10

FIG. 9—DIAGRAM SHOWING PERMEABILITY READINGS TAKEN ON A 33-INCH 3-COLUMN RADIATOR MOLD

FIG. 10—DIAGRAM SHOWING PERMEABILITY READINGS TAKEN ON A 14-INCH 5-COLUMN RADIATOR MOLD

column radiator drag is shown in Fig 9. The permeability of the various sections of this drag are designated by the permeability figures, which shows the volume of air carried off per minute. It may be noted that the permeability varies from a minimum of 15 to a maximum of 88, which indicates poor ramming. A portion of the gate, for instance, is rammed very hard, as in-

dicated by permeability of 18, while another portion is rammed to a permeability of 40, which is undoubtedly correct. When comparing the ramming of the barrels the permeability values show a variation of 33 to 48. This may be considered very good. The permeability values shown on Fig. 9 indicate the characteristic of the molds produced by molders on this floor. An examination of many floors finally resulted in locating molders on a floor of 14 inch 5 column radiator molds who ram their molds very uniform. The drag shown in Fig. 10 is a typical mold produced by these two men. The gate is rammed to a very uniform degree as indicated by the slight variation of permeability values. The barrels of this mold are rammed extremely uniform, as shown by a variation of only eight points in permeability. The permeability figures also show that these men rammed the gate a little harder than the barrel portion, thus producing an ideal mold.

Conclusion:—The permeability values shown in Figs. 9 and 10 show actual ramming condition existing in our foundries. We grant that our foundrymen are continually giving a large portion of their time to correct this non-uniform ramming. This non-uniform ramming is, as a rule, detected by the hand method or as is indicated by actual losses. Tools are devised which measure and express more accurately existing variation from a certain standard than man can possibly detect or express without the aid of these tools. With this in view, it is evident that considerable progress may be made in the uniformity and standardization of ramming in our foundries by the use of permeability of molds and other methods of measuring the degree of ramming.

Discussion

W. D. Moore: We have probably as aggravated a situation for maintaining sands as anything I know in the foundry industry. We will take 25 tons of sand as a total mass and in 24 hours we will produce out of that 200 tons of castings per day. I don't know if any of you have that problem or not. We start with a green sand mold. It is centrifugal casting and the process is relatively new. The problems of maintaining that sand are new. We have tried the maintaining of it with materials, additions other than clay first. We found very great difficulty in that on

account of the rapid burning out and depreciation, and in spite of our desires to do otherwise, we were forced to the maintaining of that sand with clay in the liquid state. It has to be mulled in, of course, with a paddle muller, and in maintaining it we have to actually work from dust and we eliminate the fine dust by the use of blowing while that sand is in the powdered state and perfectly dry. Then we add limited new sands in the form of washed silica sand and then we add our bonding material in the form of yellow clay wash, mulled in, and then it is screened and aerated and goes immediately to the molding machine. We have in extreme cases gone from dust into the mold in 30 minutes. That is a nice job to take dust and in 30 minutes temper it and produce a casting in it weighing 1,000 to 1,500 pounds.

We find these sand tests that we have developed here to be invaluable. In the miscarriage of those tests, or apparent miscarriage of them, we find the greatest enemy is the grain size of the mixture that you are dealing with. There is a definite combination of grain size to suit each particular job, and as the total mass or grain size varies from that to finer, these tests begin to miscarry, apparently. Moisture is a very sensitive element in all of them, and it becomes more and more sensitive as the fineness of your sand gets out of bounds. We find the cause of scabbing and all those things that you talk about that you can't account for largely in the fact that our grain size is out of line. When we put that grain size back in line and we observe the laws of the other tests, we stop those things that we are not able to account for otherwise.

But the point I wanted to get to you more than anything else was the fact that we are able to maintain this sand with clay easier and cheaper and surer than we are through any addition of new sand or other mediums.

H. L. Parr: I am much interested in that matter of adding 2 or 3 per cent of pitch binder for increasing dry strength. It occurs to me that perhaps that would correspondingly decrease the green strength of the sand. How about that?

H. W. Dietert: Sea coal will decrease the strength more than anything else. Pitch is a binder. Pitch has fairly good green sand strength. Pitch will do this, if you add too much of it, it will make one of the nicest rotten sand heaps you ever saw to ball you up. If you add pitch when the sand is hot, that is a nice way to get the sand grains coated with pitch. Pitch melts at around 400 to 450 degrees Fahr. Using a small portion of pitch (about one per cent) will cut out over twice as much sea coal. You will really benefit the sand in the green state. But for the addition of one per cent of sea coal, in percentage of water you would have to cut at least one per cent moisture. If you are working your sand between 6 and 7, you couldn't work it there, it wouldn't take that much water; you would have to add less water to it, because you made it absorb less water. You would have to work it down lower on the water scale. Instead of adding 160 gallons, you would have to add possibly 150. But

it does not necessarily affect your green strength. It does make it feel funny, but it works remarkably well. On the feel of molding sand, as a rule, we want our sand to feel nice, but a nice feeling sand doesn't necessarily produce a very low loss. I can show you some of the more open sands that will give us just as nice a casting as a real velvety sand.

H. H. Nixon: I would like to ask Mr. Moore (he produced the 200 tons of gray iron, I suppose, in 25 tons of sand) didn't that sand get pretty warm, and what method do you use to get that cool in that length of time?

W. D. Moore: I will say "Yes" to your question, that it does get pretty warm. That sand enters the shake-out bins at about 500 to 600 degrees Fahr. and it doesn't change materially in passing through that bin into the reciprocator. It is so hot entering the reciprocator that it will not take moisture, so that we return into it at that point tempered sand. It will take tempered sand but it will throw off moisture just like a hot stove throws it off. So we return a certain amount of tempered sand, the same as is going through the ramming machines. Immediately that is done and turned over in the reciprocator a time or two, it is in a condition where it will take water. We immediately start shooting water to it and by the time it moves down the reciprocator a little further we put the new addition to it, of new sand, which is a purely nominal one. It passes into the paddle mixer at around 150 degrees. The addition of clay wash at that point rapidly cools it through the mulling operation of the paddle mixer, so that it passes from there to the first screen at about 125 degrees. Coming through the first screen on to the bolt, it is reduced to approximately 100 degrees, and when it passes the second screen, it is down to body temperature, so that it feels nice to the hand, just slightly warm, I should say on an average below 100 degrees. The reciprocator is a long machine, about 75 to 80 feet long, equipped with paddles and it runs with an oscillating motion, a motion like a shovel, like 100 shovels, let's say, taking the sand and moving it forward each time, advancing the sand as it goes and as the molder would turn that sand over. In other words, it is moved about 18 inches at a stroke, each time progressing forward, turned over and mixed and cooled.

H. H. Nixon: The water is added after it has gone through the reciprocator?

W. D. Moore: No, during that operation. You add your tempered sand, you add your water and you add your new sand,—you don't add all your water then of course, but you add fifty to sixty per cent of the total water content in that reciprocator, the rest of it is added in the mulling mill, in the paddle mixer, and it comes with the clay wash; the clay wash is about 50 to 60 per cent water, so you get a water addition there.

H. H. Nixon: The tempered sand is added to the other sand just as it goes into the reciprocator?

W. D. Moore: No, sir, it is added when it comes into the reciprocator from the shake-out bins, when it is at such a temperature that it won't take water and you have to reduce that temperature quickly. You can put molding sand that is tempered into that and it will hold the water and will cut the temperature of that total mass and will do it very rapidly. But if you attempted to do that with water, it is a complete failure, it simply blows all the sand and everything else out of your reciprocator.

A Member: Do you employ the dye absorption test?

H. W. Dietert: We have tried it. We use it on core sand; we don't use it on the molding sands. We use the breaking strength of the sand in place of dye absorption on heap sand. It is like measuring steel or anything else. If you have more clay in it, it is going to stand that much more pressure.

W. M. Saunders: The dye absorption test really indicates the quality of your clay. Now, we have been using the word "clay" and we are not using it in the same way. Some clays that are very useful contain only about 50 per cent of what we call clay substance. The balance is the inert matter of grain. The dye absorption test shows that, that is, it shows that a substance has so much active material, and it measures not only the fineness but, of course, first, the fineness goes with colloidal matter, it measures the colloids, which we sometimes think of as being the hydrate of alumina, or the silicate of alumina, which is theoretical clay, and the hydrate of iron and the various colloidal conditions that these compounds exist in. So that in answering your question, it does, as Mr. Dietert says, measure them all, but the dye absorption test takes some little time to do and these shorter tests are much more satisfactory for control work. But, really, I wouldn't care to pass on a new sand without having the dye absorption.

Chairman R. F. Harrington: Gentlemen, there is one thing that has been brought up that I think I might be able to add a little something on from our personal experience. That is, the gentleman who spoke about the question of the effect of pitch. He mentioned the question of green sand strength, whether or not it would not affect the green sand strength, and Mr. Dietert answered it by saying it would tend to decrease the green sand strength, particularly if it were used with the same amount of sea coal; but he warned you that it should be used to a lesser amount.

In that connection I might point out the serious effect, to you gentlemen who use sea coal, the serious effect of variation in sea coal in relation to the grain, or what one might call the sieve test, simply because if you are using a coarse sea coal, your permeability of the heaps as they are affected by that proportion of sea coal will be one thing.

The Effect of Mulling on the Physical Properties of Foundry Sands

By A. V. Leun*, Ithaca, N. Y.

The effect of mulling time on the properties of molding sands has always been an interesting topic for discussion and several writers have described the results of their experiments along these lines.

In 1920, H. W. Dietert[1] conducted a test on bonded Ottawa silica sand. He mulled the sand dry for 3 minutes and then for 6 minutes at a certain water content, after which the properties of the material were tested. Wolf and Grubb[2] have also published an interesting paper in which they presented data showing the effects of mulling on the sand. They used seven mixtures and mulled them for 120 minutes, sampling and testing the sand at certain specified periods of time. The exact moisture content during the tests is not, however, stated, and was apparently not determined. R. F. Harrington[3], of the Hunt Spiller Corporation, has run mulling tests on several mixtures of Milville gravel and heavy sand. He mulled the sand for 30 minutes, sampling it at intervals of 2 or 3 minutes and testing it for bond and permeability.

It seemed to the writer, therefore, that a more detailed series of studies might throw some further light on the problem, and it was with this object in view that the experiments described in this paper were undertaken.

Apparatus and Procedure

In performing the experiment described here a Simpson number O muller was employed. Fourteen sands were tested and three runs were made on a sand each at a different water content. Approximately 120 pounds of sand was used per run. At the termination of each run the sand was discarded and a fresh unmulled batch was used. In several instances there was not enough sand to make three runs and so only two could be made.

*Cornell University.
[1] Unpublished manuscript.
[2] American Foundrymen's Association, Trans., Vol. XXXII, part 2, p. 1.
[3] Personal communication.

The sand was mixed with a certain definite amount of water, as thoroughly as possible, with the aid of a shovel, corresponding to "cutting" in the foundry. This sample was placed in the muller and after the muller was started samples were taken at the end of 10, 30, 45, 60, 75, 90, 105 and 120 minutes. Each sample was placed in an airtight container to be tested sometimes immediately and never later than four hours afterward.

On the first run in the muller tests were made for moisture, permeability, and compressive strength.

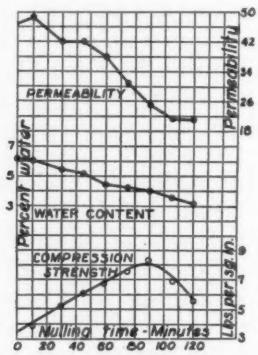

FIG. 1—PERMEABILITY AND COMPRESSION CURVES FOR SAND MULLED IN OPEN MULLER

The results of this series of tests are plotted in Figure 1. It was apparent from observing the results, that in mulling, the air currents formed by the mullers caused the sand to lose water quite rapidly. This in turn caused the permeability to continually decrease and caused the strength to reach a peak past which the water content was too low to allow the strength to increase. Furthermore, the sand became quite warm, due to the friction between the sand grains themselves and the mechanical parts of the muller. This heat also aided in driving off some of the moisture. Conditions in the foundry likewise affected the rate of evaporation; it was these external conditions that made the subsequent water control difficult to maintain with exactness.

To maintain the water content as near constant as possible

a canvas hood was made to fit the muller. Several runs were made to determine the rate of evaporation of the moisture from the sand with the hood in position. At the start of mulling, water was lost to the air inside the hood. When this air became saturated the loss of water dropped to the small amount that escaped through the hood. However, when the air currents were stopped by the hood, the temperature of the sand rose higher and moisture was forced out of the sand and caused the air under the hood to become super-saturated. Condensation on the metallic sides of the muller resulted and this condensation was greatly affected by the atmospheric conditions outside the muller.

Having determined the approximate loss of water for each period of mulling, the mulling processes were resumed. A certain definite amount of water was added to the sand every 15 minutes through a small hole in the top of the hood.

On all of the samples taken from this time on determinations were made for moisture, permeability, compression, tension, and fineness. The apparatus for performing the tension test is illustrated in a paper[4] to be presented before this convention. To determine the fineness the standard A. F. A. sieve test was employed. The sand retained on each sieve was weighed and retained for further examination under the microscope. From the sieve weighings coarseness figures were computed by the method outlined by D. W. Trainer[5], of Cornell University. By this method the weight of sand caught on a sieve is divided by the mesh of that sieve. The sum of all of the quotients for the set of sieves is the coarseness figure.

Photo-micrographs were taken of several runs in order to study the effects produced on the sand as the mulling continued from 0 to 120 minutes.

Sands Employed in Experiment

Sands of different degrees of average coarseness were employed in order to get as wide a variety as possible. Fourteen sands in all were tested and to each sand a number is assigned

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[4] Adams, T. C., *Strength Tests of Foundry Sands*, Advanced Preprint 26-1, A. F. A., 1926, pp. 48, 59 to 62 and 80, 81. See also A. F. A. Trans., vol. 34, pp. 404-492.
[5] Trainer, D. W., *Some Experiments on the Refractories of Molding Sand*, Advance Preprint 26-27, p. 13, A. F. A., 1926. See also A. F. A. Trans. vol. 34, p. 338.

for purposes of references in this paper. The list of sands and their numbers are tabulated in Table 1.

The data of Tables 3, 5 and 6 show how the compressive strength, tensile strength and the permeability varied with the increase in mulling with different water contents.

In the majority of cases, particularly with the finer sands, both the tensile and compressive strengths of the sand reach a

Table 1

SANDS USED IN INVESTIGATION

Sand No.	Name or Composition of Sand	
1	Rockport No. 2 sand.	
2	Tuscarora No. 2 sand.	
3	Albany-00.	
4	Albany-1.	
5	Albany-2.	
6	Heap sand.	
7	Heap sand	50 per cent
	Lumberton No. 2	50 per cent
8	Heap sand	66 per cent
	Burnt sand	16 per cent
	A-2 sand	10 per cent
	Gravel	8 per cent
	Clay	1.8 pounds
9	Heap sand	66 per cent
	A-2 sand	26 per cent
	Sea coal	4 per cent
	Gravel	4 per cent
10	Heap sand	32 per cent
	Burnt sand	42 per cent
	A-2 sand	21 per cent
	Gravel	5 per cent
11	Sand No. 10 plus 4.5 lbs. of patented clay bond.	
12	A-2 sand	75 per cent
	Milville gravel	25 per cent
13	Milville gravel	60 per cent
	Clean gravel	24 per cent
	A-2 sand	16 per cent
14	Milville gravel.	

peak between 75 and 105 minutes of mulling. Past this peak the strength does not decrease as a rule. In the coarser sands the peak does not appear as early in the mulling unless the water content of the sand is too low.

The permeability, while quite jumpy during the mulling, generally increases as the mulling progresses unless too little water is present in the sand. In such a case, the permeability would appear to decrease slightly. The increase or decrease in the permeability values, whatever the case may be, is not uniform, as the data will show. This is more striking in the finer sands and also those having a fairly high percentage of clay.

In studying the effects of mulling on the various properties of molding sands, each property will be taken up individually and discussed in detail.

Compressive Strength

The ability of a sand to withstand a comprehensive stress exerted upon it is dependent upon certain factors of more or less importance. These factors, in their order of importance from the writer's viewpoint, are listed as follows:

1. Distribution of the sand grains and clay throughout the mass of sand.
2. The average coarseness figure of the sand.
3. The shape of the sand grains.
4. The clay content of the sand.
5. The water content at which the sand is worked.

The last four properties listed above can be determined quite accurately for a sand, but the first and most important one is quite variable and the only way in which it can be determined is by microscopic examination of the sand. This shows the clay content to vary considerably in its distribution.

When a sand is mixed by means of a shovel the distribution of the clay is poor. It is true that "cutting" the sand works it, but the amount of working imparted to the sand is far from sufficient. The muller greatly improves the distribution of the bond and the sand grains and is responsible to a great extent for the increased strength of the sand after mulling.

The average coarseness figure or the average grain size of the sand remains fairly constant during mulling, but this will be discussed later. However, the relation between the grain size and the strength of the sand will be considered here. It does not appear that there is any relation between the compressive strength of a sand and the coarseness figure of the sand, but from the writer's experience with various sands it does appear that there is a definite relationship existing between strength, coarseness figure and clay content.

The shape of the sand grains appears to have an influence on the compressive strength of the sand. When a sand is com-

posed of rounded grains, the contact between the grains is presumably point contact, although not necessarily so in all cases. When a sand is composed of angular grains, the contact between the grains is not the same as that of the rounded grains. With rounded grain sands there can not be much interlocking, while with the angular shaped ones, the grains can and do appear to interlock with each other. If a rounded grain sand is compressed it would seem logical that the grains should slide on each other to a degree dependent on the amount of compression applied to the sand. Once they started to slide the mass of sand would no longer possess its original strength. On the other hand, if angular-grain sand is compressed, the sand grains, being interlocked, tend to resist the compression since they are less able to shift, and therefore when the sand fails it fails sharply and not as soon as the round grained sand. Assuming that both samples were given the same amount of ramming, had approximately the same coarseness figure and approximately the same clay content, as well as having nearly the same uniformity of distribution, the angular sand should show a greater strength than the rounded one.

The clay content affects the compressive strength of the sand by acting as a bond to hold the sand grains together and also as a cushion to movements of the grains within the sand due to outside forces. It would seem that the greater the clay content in a sand, the greater would be the comprehensive strength of the sand, up to a certain percentage of clay, providing that the coarseness figure of the sand remained nearly constant and the distribution nearly the same in the various samples.

The water content affects the compressive strength of the sand in that it unites with the clay substance in the sand, increasing its efficiency as a bond. For every sand and every clay content there must be a point of maximum cohesiveness, which develops with the best or optimum water content.

Of the five tabulated factors, two of them remained constant. The shape of the grains remained the same and the water content was kept as nearly constant as possible throughout any one test. The clay content and the coarseness figure did not vary to such an extent as to have any appreciable effect on the resulting com-

pressive strength of the sand. Therefore, the only remaining factor, the distribution of the sand grains and clay, would seem to be the cause of the strength rising with continued mulling.

Table 3 gives data comparing the compressive strength versus mulling time. In all cases the strength is seen to increase with more or less rapidity with the time of mulling up to 75 minutes. Past this time some of the sands continue to increase in strength while others cease to gain in strength. The percentage increase with respect to the initial strength of the sand is tabulated in Table 2 for each sand for mulling periods of ten, thirty, sixty, and one hundred and twenty minutes.

Table 2

SHOWING THE PERCENTAGE INCREASE IN THE STRENGTH OF THE SAND WITH RESPECT TO THE INITIAL STRENGTH BEFORE MULLING—FOR MULLING TIMES OF 10, 30, 60 AND 120 MINUTES

Sand No.	Water Per Cent	Mulled 10 Minutes	Mulled 30 Minutes	Mulled 60 Minutes	Mulled 120 Minutes
1	5.2	10.0	22.5	46.2	81.2
1	6.2	5.0	8.0	11.0	15.0
1	7.6	6.1	13.4	20.6	13.4
2	5.3	17.4	37.2	55.8	....
2	6.5	10.2	23.4	36.8	....
2	8.5	5.4	11.8	19.1	....
3	5.0	12.5	28.3	35.8	41.5
3	6.0	16.6	44.0	80.0	....
3	8.2	33.0	56.0	77.0	11.0
4	4.5	9.3	25.2	40.0	13.4
4	5.2	8.0	21.0	40.3	....
5	4.0	15.4	30.3	39.9	45.4
5	5.3	42.4	77.0	102.8	100.0
5	6.5	21.4	37.1	51.4	51.3
6	4.2	8.3	20.8	29.8	14.8
6	6.0	29.9	59.9	73.0	75.0
6	7.4	18.2	36.3	45.4	68.2
7	5.4	16.2	31.0	46.5	....
7	7.0	22.6	40.0	51.2	....
7	8.2	21.3	34.3	39.4	....
8	5.8	7.5	52.5	70.0	60.0
8	6.5	18.2	....	54.4	36.8
8	7.5	21.0	29.0	57.8	73.3
9	4.7	5.5	16.2	32.4	81.0
9	6.5	5.9	14.7	29.9	76.5
10	6.0	12.7	25.7	32.2	45.1
11	7.0	8.1	12.2	22.4	28.5
12	5.0	21.6	40.0	53.3	60.0
12	6.0	19.5	36.8	50.0	....
12	6.8	20.0	42.5	57.5	75.0
13	4.0	27.5	51.2	60.0	52.5
13	5.6	20.0	35.0	42.5	43.6
13	8.0	9.2	18.3	26.3	28.8
14	6.0	8.7	22.5	33.7	....
14	7.0	6.0	20.0	39.0	....

Upon examination of Table 2 of percentage increases due

to mulling it is evident that the amount of water that is added to the sand before placing it in the muller is very important.

If the sand is mulled with too little water the sand grain will be very uniformly worked because the clay in the sand will not have plasticity enough to interfere with the thorough mixing of the sand. However, the clay will not all be utilized as some

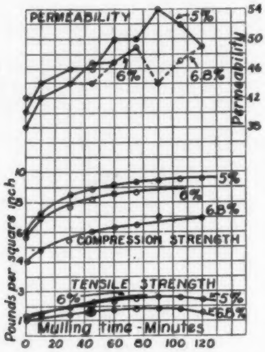

FIG. 2—SHOWING EFFECT OF ADDING TOO MUCH WATER

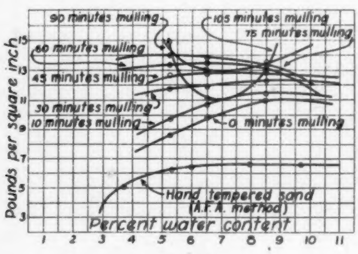

FIG. 3
COMPRESSION VERSUS WATER CONTENT CURVE FOR SAND No. 2

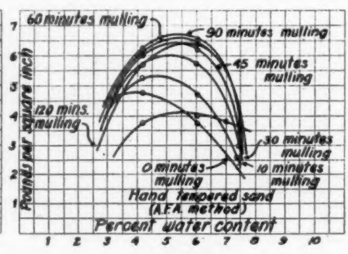

FIG. 4
COMPRESSION VERSUS WATER CONTENT CURVE FOR SAND No. 6

of it will not receive sufficient water to make it perform its purpose in the sand. Some of the clay, therefore, will remain fairly dry and will occupy the voids in the sand and will act as fine silt. In such a case the increase in strength due to mulling will not be as great as when sufficient water is added.

If too much water is used during the mulling of the sand

the clay may lose some of its effectiveness due to too much water being absorbed by it. In this case, if the sand contains fifteen per cent or more of clay, the latter becomes so sticky that it prevents the muller from throwing the sand around and intimately mixing it. In such a case the increase in comprehensive strength will be less than when the optimum water content is added. In Fig. 2 the effect produced by adding too much water to the sand may be observed. In this case, as also for sand 13, the sand having the greatest amount of water in it gave the lowest compression curve. Other cases could be cited, but these are the most defined of the set.

From the data of Table 3 points were taken and these points plotted as pounds per square inch against per cent water in the sand. These curves were plotted for sands Nos. 2, 6, 7 and 12. For each of these sands curves were plotted for the same sand tempered by hand according to the A. F. A. method. The curves for sands Nos. 2 and 6 are shown in Figs. 3 and 4.

Fig. 3 is the group of curves for sand No. 2, which is a very fine sand, containing approximately nineteen per cent clay. This sand was "cut" very carefully before being placed in the muller and, even at zero mulling, the strength at all water contents is greater than the corresponding strength for the hand tempered sand. This is an interesting fact. It is to be observed that, as the mulling is continued, the compressive strength of the sand increases for all water contents. This continues until the sand has been mulled for seventy-five minutes. At ninety minutes the strength begins to fall off and continues to fall at one hundred and five minutes' mulling. The reason for this drop appears to be due to the fact that the sand is a very fine one. As this sand is mulled and is rolled over by the heavy wheel in the muller, it is mixed quite intimately. The clay content is distributed more and more evenly throughout the mass of the sand and the grain distribution is also greatly improved. However, a time is reached when continuous working will fail to produce any better mixture. The clay, being continually mulled, will be finely divided and the water in the sand will be absorbed and used to better advantage by this finely divided clay. There being no coarse grains in the sand, the clay will begin to ball up, very

slightly it is true, but this balling up progresses as the mulling continues. The result of this action will be to disturb the distribution of the sand grains and particularly the clay so that as a result the strength will fall off as is shown on the set of curves.

Table 3

COMPRESSION STRENGTH DATA OF SANDS USED IN INVESTIGATION

Mulling Time Minutes	Water Per Cent	Compression Strength	Water Per Cent	Compression Strength	Water Per Cent	Compression Strength
			Sand No. 1			
0	5.5	8.0	6.8	10.0	7.5	9.8
10	5.7	8.8	6.1	10.2	7.3	10.5
30	5.4	9.0	6.2	9.8	6.9	10.3
45	5.0	11.3	6.4	11.0	7.2	9.9
60	4.8	11.5	5.8	11.1	7.7	10.2
75	4.8	11.9	6.2	11.1	7.7	11.8
90	4.5	13.0	6.8	10.5	7.7	11.5
105	4.5	14.0	6.1	11.5	7.6	11.2
120	4.8	14.5	...	....	7.7	11.1
			Sand No. 2			
0	5.0	8.5	6.2	9.5	8.8	11.0
10	5.2	10.5	6.8	11.0	9.2	11.5
30	5.6	11.0	6.5	12.0	7.9	12.0
45	4.9	12.1	6.6	12.7	8.5	....
60	5.8	11.0	5.9	13.0	8.3	12.4
75	5.7	12.4	6.0	14.0	8.4	12.5
90	5.5	14.8	6.3	12.8	9.0	13.5
105	4.9	15.2	6.6	10.2	8.4	13.0
120	4.4	12.7	...	....	...	....
			Sand No. 3			
0	5.2	5.3	6.0	4.0	8.6	2.3
10	5.2	6.2	6.1	4.2	8.4	3.1
30	5.0	6.6	6.2	4.3	7.5	...
45	5.0	6.8	6.1	4.8	8.6	3.5
60	5.0	7.1	5.7	5.4	8.3	3.9
75	4.9	7.3	5.6	5.9	8.4	3.1
90	4.7	7.5	5.4	6.6	8.0	4.2
105	4.7	7.5	...	...	8.3	4.3
120	4.8	7.5	...	...	8.1	3.9
			Sand No. 4			
0	5.0	7.6	5.1	6.2	...	...
10	5.2	8.0	5.6	6.9	...	...
30	5.1	8.8	...	7.5	...	...
45	4.7	10.5	5.6	8.1	...	...
60	4.5	10.6	5.4	8.5	...	...
75	4.2	10.0	5.4	9.0	...	...
90	4.0	10.9	4.8	9.5	...	...
105	3.9	9.6	5.3	8.5	...	...
120	3.7	9.0	4.8	9.5	...	...

(Continued on next page)

Table 3—(Continued)

Mulling Time Minutes	Water Per Cent	Compression Strength	Water Per Cent	Compression Strength	Water Per Cent	Compression Strength
			Sand No. 5			
0	4.5	3.3	5.3	3.5	6.7	3.5
10	4.5	4.1	5.3	4.5	5.9	4.2
30	4.2	4.3	5.5	6.2	6.4	4.8
45	3.8	4.4	5.4	6.7	6.8	5.0
60	3.6	4.6	5.6	6.6	7.1	5.0
75	3.6	5.0	5.3	6.3	6.8	5.2
90	3.5	6.0	5.4	7.5	...	...
105	3.5	6.1	5.2	7.1	6.3	5.4
120	3.5	6.2	5.3	7.0	6.3	5.3
0	8.5	2.8	10.3	1.8	...	...
10	8.1	3.0	9.8	1.7	...	...
30	8.0	3.1	9.5	1.9	...	...
45	7.9	3.3	9.1	2.1	...	...
60	8.0	3.4	9.0	2.5	...	...
75	8.0	3.7	9.0	2.9	...	...
90	7.6	3.9	...	...	...	...
105	7.5	4.3	...	...	...	...
120	7.4	4.8	...	...	...	...
			Sand No. 6			
0	4.6	4.8	6.1	3.4	8.0	2.2
10	4.8	5.6	6.0	4.9	7.9	2.6
30	4.3	5.8	6.2	5.5	7.6	2.8
45	4.3	...	6.3	6.1	7.4	3.0
60	4.2	6.2	6.2	6.3	7.2	3.2
75	4.3	5.6	6.1	6.2	7.1	3.3
90	4.2	6.4	6.0	6.4	7.1	...
105	3.8	5.5	5.6	6.9	7.3	3.6
120	3.8	5.4	6.3	6.5	7.2	4.0
			Sand No. 7			
0	5.4	8.7	7.4	7.8	7.8	7.6
10	5.6	9.2	7.4	11.2	8.1	9.8
30	5.4	11.2	7.1	11.4	8.3	10.1
45	5.6	11.8	6.8	11.8	8.5	10.4
60	5.2	12.6	6.9	12.0	8.4	10.6
75	5.3	13.1	7.0	12.4	8.3	10.7
90	...	....	...	....	...	....
105	...	....	...	....	...	....
120	...	....	...	....	...	....
			Sand No. 8			
0	5.8	4.0	6.9	4.4	7.8	3.8
10	5.9	4.3	6.8	5.2	7.5	4.6
30	6.0	6.1	6.6	...	7.2	4.9
45	5.9	6.6	6.4	6.2	7.0	5.6
60	5.8	6.8	6.5	6.8	7.6	6.0
75	5.8	6.6	6.7	7.0	7.7	6.1
90	5.8	6.5	6.2	6.8	7.7	6.3
105	5.8	5.8	6.5	7.0	7.6	6.4
120	5.8	6.0	7.0	6.0	7.5	6.6
			Sand No. 9			
0	5.2	3.7	6.7	3.4	7.8	3.8
10	4.9	3.9	6.6	3.5	7.5	4.6
30	4.6	4.3	6.5	3.9	7.2	4.9
45	4.6	...	6.6	4.1	7.0	5.6
60	4.9	4.6	6.6	4.5	7.6	6.0
75	4.7	5.3	6.4	4.8	7.7	6.1
90	4.7	5.8	6.0	5.5	7.7	6.3
105	4.8	6.0	5.7	6.8	7.6	6.4
120	4.6	6.8	6.2	6.2	7.5	6.6

(Concluded on next page)

Table 3—(Concluded)

Mulling Time Minutes	Water Per Cent	Compression Strength	Water Per Cent	Compression Strength	Water Per Cent	Compression Strength
	Sand No. 10				*Sand No. 11*	
0	6.2	3.2			8.0	4.9
10	6.1	3.5			8.1	5.3
30	6.0	3.5			7.6	...
45	6.1	3.5			7.5	5.5
60	6.0	4.1			7.6	6.0
75	6.0	4.2			6.5	6.2
90	5.9	4.3			6.6	6.9
105	5.8	4.5			6.6	7.0
120	5.8	4.9			7.2	6.3
			Sand No. 12			
0	5.2	6.2	6.7	5.8	7.2	4.0
10	5.0	7.0	7.0	7.0	6.5	4.8
30	4.9	8.5	6.2	7.7	6.8	5.4
45	4.9	8.9	5.9	8.2	6.6	6.1
60	5.0	9.2	5.9	8.5	6.8	6.2
75	4.9	9.3	5.8	8.8	6.9	6.5
90	5.1	9.5	...	...	6.5	7.0
105	4.9	11.2	...	...	6.6	6.8
120	4.6	12.5	...	...	7.0	6.9
			Sand No. 13			
0	4.4	9.3	5.8	7.7	8.0	7.6
10	4.1	9.8	5.6	10.2	8.1	8.2
30	4.4	12.1	5.5	10.6	8.2	9.0
45	3.8	12.4	5.2	10.9	7.9	9.3
60	4.2	12.6	5.0	11.2	7.8	9.6
75	3.9	12.6	5.6	....	8.0	9.5
90	3.8	12.2	5.8	11.4	8.3	9.7
105	3.7	12.5	6.1	11.8	8.1	9.9
120	...	....	6.3	11.8	8.4	9.8
			Sand No. 14			
0	...	....	6.2	8.0	7.4	6.7
10	...	....	6.4	8.6	7.0	6.9
30	...	....	6.1	9.6	7.0	8.1
45	...	....	5.8	10.5	7.3	8.4
60	...	....	5.5	10.7	7.2	8.8
75	...	....	6.1	10.6	6.8	9.5
90	...	....	6.3	9.9	...	...
105	...	....	...	....	...	...
120	...	....	...	....	...	...

Fig. 4 shows sand No. 6. It is coarser than an Albany No. 2 sand. The effect of water on the gain in strength can be well studied from this set of curves. With this sand the maximum strength is obtained with about six per cent water. With more water than the optimum content for maximum strength, the gain in compressive strength is small as compared with the gain at six per cent water. When less than the optimum water content is used, the gain in compressive strength is less than at

six per cent water, but more than at seven and a half per cent water. This sand is fairly low in clay and therefore when too much water was employed, the clay became too wet, and not only became less efficient itself but it made the sand a muddy mixture and retarded the mixing of the sand grains as the mulling progressed. It is interesting to note the curve for the hand tempered sand. The sand employed for making the hand test was sand that was mulled, tested, and saved and then after drying out was mixed up by hand and tested. It is evident that some of the good results brought about by mulling were still in the sand when it was hand mixed.

The set of curves for sand No. 7 is not shown. This sand has a coarseness figure about the same as sand No. 6. However, the clay content is higher. The only reason that can be given for the reverse slope of the curve representing zero mulling is that a poor sample was taken at the water content of seven per cent. Although this sand is fairly high in clay, it continues to gain in strength as the mulling is continued. No clay globules were formed at any time. The absence of these small lumps is due to the fact that the sand is a medium coarse one. As the roller operates in the muller, the coarse grains in the sand are ground on each other under the wheel so that any clay globules which attempted to form would be quickly ground up by the grinding action of the sand grains. These large grains were absent in sand No. 2, so there was no preventive against the formation of the small clay balls. The curve for the hand tempered sand is again interesting. The sand which was hand mixed was sand that had been used for making a muller test. It was allowed to dry and then after three days it was mixed by hand. It shows very plainly that much of the strength was still present in the sand even though it had dried out. We attribute this entirely to the good distribution of clay and sand grains brought about by the muller.

Sand No. 12 is coarser than No. 7. The set of curves (not shown) again clearly shows the large increase in strength that may be gained by mulling. The curve for the hand tempered sand is less than the zero mulled sand. This is because the zero mulled sand was carefully "cut" and mixed with a shovel before

being placed in the muller. The hand tempered sand was mixed up from sand that had never been mulled.

It is evident that the greater the clay content, within limits, the less steep will be the slope in the curves of strength versus water content and the greater will be the leeway as to the amount of water to use. This is evidenced by comparing the data for figure sand No. 6 with the data of the sands 2, 7 and 12. Sand No. 6 contains less clay than sand No. 7 and it is seen that the slope of the curves for sand No. 6 is steeper than the corresponding slopes for sand No. 7. The coarseness figures are about the same for the two sands.

Tensile Strength

The tensile strength of a sand, in the opinion of the writer, is dependent upon the same factors as the comprehensive strength. However, the writer would rearrange them in their order of importance. As before, we would place the distribution of the sand grains and clay as the most important factor, and the other factors in the following order—clay content of the sand, water content of the sand, shape of the grains, and coarseness figure of the sand.

The clay content together with the water per cent employed in the sand is of much importance in respect to the tensile strength obtained in a sand. A sand possessing a low clay content cannot be as strong as a sand having a higher clay content, assuming that the two sands have approximately equivalent coarseness figures. In a sand having a low clay content it is very important that every bit of the clay in the sand be utilized as a binder so that the tensile strength obtained will be as near the maximum strength as possible. Unless all of the clay is employed in coating the grains of the sand, maximum efficiency of the clay content will not be obtained. That all of the clay is so utilized is probably never the case. However, it is our aim to produce such a condition and in order to get as near that condition as possible the clay and the sand should be mulled. It is more important to develop or increase the tensile strength of a sand than it is to increase its compressive strength. It

follows, however, that as we increase one of the two, the other one will increase also.

A sand having a fairly high clay content will yield a higher tensile strength when given the same working as a sand of the lesser clay content. Even with poor distribution, a fairly good tensile strength will be obtained from the former sand. However, even this type of sand should be mulled to develop as much of its intrinsic strength as possible.

In Table 5 is given data from which one can plot the tensile strength versus mulling time for all of the sands tested. In every case it is observed that the tensile strength increases with longer mulling times up to about 90 minutes. Past this point a few of the curves fall off slightly.

In Table 4 are tabulated the percentage of tensile strength increases with respect to the initial tensile strength of each sand for mulling times of ten, thirty, sixty, and one hundred and twenty minutes. Upon closer examination of this table several interesting facts can be observed.

For the sake of convenience we will refer to sands as either fine, semi-coarse, or coarse. This is merely to facilitate the review of Table 4. The fine sands include numbers 1, 2, 3 and 4. The semi-coarse sands include numbers 5, 6, 7, 8, 9, 10 and 11. The coarse sands include numbers 12, 13 and 14.

Considering the fine sands first, it is seen that the tensile strengths of these rise more rapidly when the sands are mulled drier than the optimum water content calls for. The explanation for this in the opinion of the writer is as follows: As the sand is placed in the muller the clay has absorbed most of the water added to the sand. However, this clay is not uniformly distributed. Some of the grains of the sand are free of clay while other grains are coated very heavily and unevenly with colloidal material. Let us assume that six or seven per cent of water is in the sand, and the mulling operation is started. In rolling and turning the sand, the clay particles are at first broken up into smaller and finer ones. In grinding the clay particles to smaller size, distribution is also started. However, due to the absence of coarse grains in the sand, the clay will not be broken up past a certain point, but instead the clay will ball up and

thus will not be suitable for coating the grains. Therefore the tensile strength will not increase as rapidly as it would otherwise.

On the other hand, suppose that five per cent water was added to the sand and the mulling operation was started. There not being sufficient water to satisfy the need of all of the clay in

Table 4

SHOWING THE PERCENTAGE INCREASE IN THE TENSILE STRENGTH OF THE SAND WITH RESPECT TO THE INITIAL STRENGTH BEFORE MULLING—FOR MULLING TIMES OF 10, 30, 60 AND 120 MINUTES

Sand No.	Water Per Cent	Mulled 10 Minutes	Mulled 30 Minutes	Mulled 60 Minutes	* Mulled 120 Minutes
1	5.0	35.0	60.0	112.0	141.0
1	6.2	39.5	55.0	61.1	....
1	7.6	47.0	60.0	....	89.7
2	5.3	50.0	56.3	100.0	81.0
2	6.5	4.9	52.4	71.4	....
2	8.5	8.8	17.2	47.6	52.1
3	5.0	57.1	71.4	100.0	171.4
3	6.0	1.0	60.0	80.0	....
3	8.2	0.0	0.0	0.0	0.7
4	4.5	0.0	33.0	50.0	18.6
4	5.2	7.1	21.4	43.0	....
5	4.0	25.0	50.0	100.0	137.5
5	5.3	10.0	40.0	....	65.0
5	6.5	10.0	15.0	30.0	90.0
6	4.2	25.0	50.0	62.5	50.0
6	6.0	24.0	60.4	75.0	123.5
6	7.4	0.0	0.0	54.5	72.7
7	5.4	41.2	64.1	85.3	....
7	7.0	84.7	115.4	161.6	....
7	8.2	32.2	46.6	66.6	....
8	5.8	50.0	108.3	108.3	108.3
8	6.5	26.3	52.6	73.6	84.2
8	7.5	80.0	120.0	180.0	260.0
9	4.7	7.1	42.8	85.7	157.1
9	6.5	5.0	10.0	35.0	....
10	6.0	50.0	60.0	66.6	83.3
11	7.0	18.1	45.4	45.4	18.1
12	5.0	11.5	38.4	77.0	92.3
12	6.0	30.0	50.0	83.3	....
12	6.8	25.0	40.0	60.0	70.0
13	4.0	50.0	94.4	90.0	94.4
13	5.6	42.3	61.5	96.1	134.6
13	8.0	....	....	....	....
14	6.0	25.6	30.2	37.2	....
14	7.0	8.3	11.1	11.1	....

the sand, part of the clay will at first remain fairly dry while the rest of the clay will absorb the water and come out of the voids in the sand. However, as the mulling continues the water will be more uniformly distributed through the clay substance. None of the colloidal material will be over saturated. With this

Table 5

TENSILE STRENGTH DATA OF SANDS USED IN INVESTIGATION

Mulling Time Minutes	Water Per Cent	Tensile Strength	Water Per Cent	Tensile Strength	Water Per Cent	Tensile Strength
			Sand No. 1			
0	5.5	1.6	6.8	1.9	7.5	1.7
10	5.7	2.3	6.1	2.5	7.3	2.5
30	5.4	2.7	6.2	2.8	6.9	2.7
45	5.0	3.7	6.4	3.1	7.2	2.8
60	4.8	3.6	5.8	2.9	7.7	2.4
75	4.8	3.8	6.2	2.6	7.7	2.9
90	4.5	4.2	6.8	2.7	7.7	3.2
105	4.5	4.1	6.1	2.7	7.6	...
120	4.8	4.1	...	...	7.7	3.2
			Sand No. 2			
0	5.0	1.6	6.2	2.1	8.8	2.3
10	5.2	2.4	6.8	2.2	9.2	2.5
30	5.6	2.5	6.5	3.2	7.9	2.7
45	4.9	2.9	6.6	3.8	8.5	3.2
60	5.8	3.2	5.9	3.6	8.3	3.4
75	5.7	3.0	6.0	...	8.4	3.6
90	5.5	3.6	6.3	3.0	9.0	3.8
105	4.9	3.1	6.6	2.8	8.4	3.5
120	4.4	2.9	...	...	...	...
			Sand No. 3			
0	5.2	0.7	6.0	0.5	8.6	0.7
10	5.2	1.1	6.1	0.6	8.4	0.7
30	5.0	1.2	6.2	0.8	7.5	0.7
45	5.0	1.3	6.1	0.8	8.6	0.7
60	4.9	1.4	5.7	0.9	8.3	0.7
75	4.7	1.5	5.6	1.0	8.4	0.75
90	4.7	1.7	5.4	1.1	8.0	0.75
105	4.7	1.8	...	...	8.3	0.75
120	4.8	1.9	...	...	8.1	0.75
			Sand No. 4			
0	5.0	1.8	5.1	1.4	...	...
10	5.2	1.9	5.6	1.5	...	...
30	5.1	2.4	...	1.7	...	...
45	4.7	2.0	5.6	1.8	...	...
60	4.5	2.7	5.4	2.0	...	...
75	4.2	2.7	5.4	1.8	...	...
90	4.0	2.8	4.8	2.2	...	...
105	3.9	2.5	5.3	2.0	...	...
120	3.7	2.1	4.8	...	...	...
			Sand No. 5			
0	4.5	0.8	5.3	1.0	6.7	1.0
10	4.5	1.0	5.3	1.1	5.9	1.1
30	4.2	1.2	5.5	1.4	6.4	1.1
45	3.8	1.4	5.4	1.5	6.8	1.2
60	3.6	1.6	5.6	...	7.1	1.2
75	3.6	1.7	5.3	1.7	6.8	1.4
90	3.5	1.8	5.4	1.8	...	...
105	3.5	1.8	5.2	1.6	6.3	1.5
120	3.5	1.9	5.3	1.6	6.3	1.9
0	8.5	0.9	10.3	0.7	...	...
10	8.1	1.0	9.8	0.7	...	...
30	8.0	1.0	9.5	0.8	...	...
45	7.9	1.1	9.1	0.9	...	...
60	8.0	1.1	9.0	1.1	...	...
75	8.0	1.2	9.0	1.1	...	...
90	7.6	1.2	...	...	...	...
105	7.5	...	...	...	...	...
120	7.4	1.3	...	...	...	...

(Continued on next page)

Table 5—(Continued)

Mulling Time Minutes	Water Per Cent	Tensile Strength	Water Per Cent	Tensile Strength	Water Per Cent	Tensile Strength
			Sand No. 6			
0	4.6	0.8	6.1	0.85	8.0	0.55
10	4.5	1.0	6.0	1.0	7.9	0.55
30	4.3	1.2	6.2	1.3	7.6	0.55
45	4.3	1.0	6.3	1.4	7.4	0.70
60	4.2	1.3	6.2	1.45	7.2	0.85
75	4.3	1.25	6.1	1.5	7.1	0.85
90	4.2	1.1	6.0	1.6	7.1	....
105	3.8	1.2	5.6	2.2	7.3	0.90
120	3.8	1.2	6.3	1.9	7.2	0.95
			Sand No. 7			
0	5.4	1.7	7.4	1.3	7.8	1.55
10	5.6	2.4	7.4	2.4	8.1	2.05
30	5.4	2.8	7.1	2.8	8.3	2.20
45	5.6	3.2	6.8	3.1	8.5	2.25
60	5.2	3.15	6.9	3.4	8.4	2.50
75	5.3	3.2	7.0	3.6	8.3	2.70
			Sand No. 8			
0	5.8	0.6	6.9	0.9	7.8	0.5
10	5.9	0.9	6.8	1.2	7.5	0.9
30	6.0	1.25	6.6	1.4	7.2	1.1
45	5.9	1.25	6.4	1.6	7.0	1.3
60	5.8	1.25	6.5	1.65	7.6	1.4
75	5.8	1.25	6.7	1.35	7.7	1.4
90	5.8	1.25	6.2	1.65	7.7	1.6
105	5.8	1.25	6.5	1.55	7.6	1.65
120	5.8	1.25	7.0	1.75	7.5	1.8
			Sand No. 9			
0	5.2	0.7	6.7	1.0	7.8	0.5
10	4.9	0.75	6.6	1.1	7.5	1.0
30	4.6	1.0	6.5	1.1	7.2	1.1
45	4.6	1.1	6.6	1.2	7.0	1.4
60	4.9	1.3	6.6	1.3	7.6	1.45
75	4.7	1.3	6.4	1.5	7.7	1.6
90	4.7	1.4	6.6	1.55	7.7	1.6
105	4.8	1.45	5.7	1.30	7.6	1.65
120	4.6	1.80	6.2	....	7.5	1.7
	Sand No. 10				*Sand No. 11*	
0	6.2	0.6			8.0	1.1
10	6.1	0.9			8.1	1.3
30	6.0	0.95			7.6	1.6
45	6.1	0.95			7.5	1.45
60	6.0	1.0			7.6	1.6
75	6.0	1.05			6.5	1.5
90	5.9	1.05			6.6	1.6
105	5.8	1.1			6.6	1.6
120	5.8	1.1			7.2	1.3
			Sand No. 12			
0	5.2	1.3	6.7	1.2	7.2	1.0
10	5.0	1.45	7.0	1.55	6.5	1.25
30	4.9	1.85	6.2	1.85	6.8	1.40
45	4.9	2.05	5.9	2.05	6.6	1.50
60	5.0	2.25	5.9	2.15	6.8	1.60
75	4.9	2.40	5.8	2.55	6.9	1.75
90	5.1	2.55	...	....	6.5	1.90
105	4.9	2.30	...	....	6.6	1.65
120	4.6	2.50	...	....	7.0	1.70

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Table 5—(Concluded)

Mulling Time Minutes	Water Per Cent	Tensile Strength	Water Per Cent	Tensile Strength	Water Per Cent	Tensile Strength
			Sand No. 13			
0	4.4	1.8	5.8	1.3	...	....
10	4.1	2.7	5.6	1.85	...	....
30	4.4	3.5	5.5	2.10	...	....
45	3.8	3.4	5.2	2.35	...	....
60	4.2	3.3	5.0	2.55	...	....
75	3.9	3.4	5.6	....	...	....
90	3.8	3.4	6.1	2.60	...	....
105	3.7	3.4	6.1	2.85	...	....
120	...	3.4	6.3	3.05	...	....
			Sand No. 14			
0	6.2	2.2	7.4	1.8	...	....
10	6.4	2.7	7.0	1.95	...	....
30	6.1	2.8	7.0	2.1	...	....
45	5.8	2.8	7.3	2.0	...	....
60	5.5	2.9	7.2	2.0	...	....
75	6.1	2.8	6.8	2.1	...	....
90	6.3	2.4	...	...	...	....

condition prevailing, the clay will offer very little resistance to being reduced by the grinding action because its plasticity is not as high as if the sand contained a higher percentage of water. As the mulling continues further, the continual working of the clay will increase its plasticity and as this occurs the clay will adhere to the faces of the grains and will be worked on by the inter-rubbing between the grains. If too much clay adheres to a grain of sand it will be ground off and utilized later by other grains of sand. In this manner the clay is utilized to the best advantage and we obtain a great increase in the tensile strength of the sand when it is tested.

The semi-coarse sands are intermediate between the fine and the coarse ones. The coarse sands will be reviewed as they act the same as the semi-coarse sands, but their action is more pronounced and distinctive as they contain a greater percentage of coarse grains than do the semi-coarse sands. With a coarse sand while it may be advantageous in certain instances to mull the sand with too little water in it, this is not always the case, as in the fine sands. In examining the data in Table 4 it is observed that the greatest increase in tensile strength in the semi-coarse and coarse sands did not always occur when the sand contained less than the optimum water content. In fact, four of the seven

sands considered gave the greatest tensile strength increases when the optimum water content was present in the sand. Therefore it would appear that when sands, coarser than an Albany 2 sand, are mulled the water added to the sand does not have such an influence on the day distribution as with finer sands. The possible reason for this is that when a semi-coarse or coarse sand is mulled the clay does not act as it does in a fine sand. In a coarse sand there are present many fairly large grains in the mass of sand. These grains act as additional grinding devices to reduce the clay. As the heavy roller operates in the muller, the sand grains and clay are intermixed. If the clay starts to ball up it is very liable to be caught between some of the coarser grains in the sand. Then as the roller passes over these grains they will grind the clay up again and in doing so will force some of the clay to become attached to the grains of sand. In this way the clay is well mixed among the sand grains and is practically ground onto the faces of the grains. In studying Table 4 it would be interesting to compare it with the results tabulated in Table 2, which is the same table as 4, except that it shows compressive strength increases. Sands Nos. 1, 2, 4, 5, 6, 7, 9 and 13 show the maximum increases in strength, compared to the initial strength, at the same water content for both tension and compression. The other sands do not agree on the same water content.

From the data of Table 5, showing tensile strength versus mulling time, points were taken for five of the sands and curves of tensile strength versus water content for the five sands were plotted. The curves for sands Nos. 2 and 6 may be seen in Figs. 5 and 6, respectively.

The first one of these series of curves that I will discuss is that for sand No. 2 (Fig. 5), which is a very fine sand. The tensile strength of the sand increases up to a mulling time of seventy-five minutes. Past this point the clay, as was described on a previous page, no longer acts as a coating for the grains but begins to join with other particles of clay and forms small lumps of this substance. This naturally will cause the deposition of the clay on the grains to cease and the reverse process

may possibly set in. The curve for the hand tempered sand is flatter than for the mulled sand, thus showing less variation in strength with different water contents.

Sand No. 5, an Albany No. 2 sand, having much less clay than the previous one and being coarser grained, shows fairly steady increases in tensile strength up to one hundred and five minutes' mulling, when at one hundred and twenty minutes' mulling it falls off slightly at the higher water content. To the writer the only apparent reason for this decrease may be that the clay, having been worked so long, decreased in plasticity with the continual addition of water to the sand as the mulling progressed.

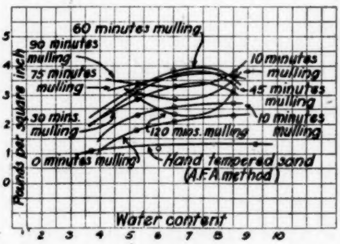

FIG. 5
TENSION VERSUS WATER CONTENT CURVE FOR SAND No. 2

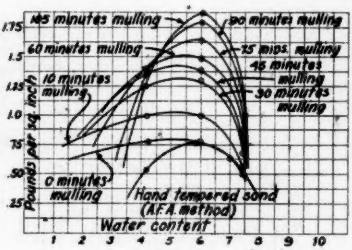

FIG. 6
TENSION VERSUS WATER CONTENT CURVE FOR SAND No. 6

Sand No. 6 is plotted on Fig. 6. This sand is coarser grained than an Albany 2 sand. It shows rapid increases in tensile strength for all water contents up to sixty minutes' mulling. Past that point the tensile strength still increases for water contents above 4.5 per cent. At this water content the tensile strength of the sand decreases. The possible reason for this is that because of the water being so low in the sand the clay lost some of its plasticity after sixty minutes' mulling and failed to cling to some of the sand grains, thus destroying part of the sand's tensile strength.

The curves for sand No. 7 (not shown) showed strength increases as long as the sand was mulled which was up to seventy-five minutes. The curve representing the hand tempered sand shows higher strength than the zero mulled sand. The sand that

was hand tempered was sand that had been mulled, tested and then saved and later was hand tested according to the A. F. A. method. It shows that even though the sand was allowed to dry out and then be mixed by hand it still retained some of its potential strength imparted to it by mulling.

Sand No. 12 (curve not shown) has nothing unusual about its set of curves other than the fact that the tensile strength of the sand increases fairly uniformly for the range of water contents employed. The curves illustrate very plainly the advantage gained by mulling the sand, as have the other curves used in this report, and they need no further interpretation than has been given them.

Permeability

The permeability of a sand appears to be dependent upon—

1. The distribution of sand grains and clay.
2. Coarseness of the sand.
3. Clay content.
4. Water content.

Of these factors Nos. 2 and 3 were maintained almost constant for each run. No. 4 was maintained as constant as was possible. One variable that could not be maintained constant was the distribution. This distribution in turn is dependent upon the water content of the sand and on the time of mulling. It is also dependent, in part, on the coarseness of the sand and the clay content, as was explained in an earlier part of the paper.

From the permeability versus mulling time data for the 14 sands tested shown in Table 6, it is seen in almost every case that the permeability increases as mulling progresses, but it does not increase in a uniform manner, as the curves show.

Assuming that a sand is well mixed with the aid of a shovel and is placed in the muller for working, we will trace what happens in most cases of mulling. As the muller works the sand, the distribution of grains becomes more uniform and the clay is taken out of the voids and forced to coat the sand grains. This action does not occur rapidly, but progresses as the time of mulling grows. The clay, being drawn out of the voids onto the surface of the grains, will cause some of the finer ones to cling to it. This action

Table 6

PERMEABILITY DATA OF SANDS INVESTIGATED

Mulling Time Minutes	Water Per Cent	Permea-bility	Water Per Cent	Permea-bility	Water Per Cent	Permea-bility
			Sand No. 1			
0	5.5	2.4	6.8	3.1	7.5	2.6
10	5.7	2.9	6.8	3.1	7.3	2.6
30	5.4	2.4	6.2	3.1	6.9	2.4
45	5.0	2.2	6.4	3.3	7.2	3.1
60	4.8	2.2	5.8	3.3	7.7	3.1
75	4.8	2.2	6.2	3.3	7.7	3.5
90	4.5	2.2	6.8	4.0	7.7	2.9
105	4.5	2.2	6.1	3.3	7.6	3.5
120	4.8	2.2	...	...	7.7	3.1
			Sand No. 2			
0	5.0	4.9	6.2	8.5	8.8	10.0
10	5.2	4.2	6.8	9.0	9.2	11.8
30	5.6	4.2	6.5	8.6	7.9	8.6
45	4.9	4.9	6.6	7.5	8.5	9.0
60	5.8	7.6	5.9	5.6	8.3	12.6
75	5.7	7.6	6.0	4.9	8.4	13.6
90	5.5	8.2	6.3	4.7	9.0	15.2
105	4.9	8.4	6.6	7.7	8.4	9.7
120	4.4	5.3	...	...	...	...
			Sand No. 3			
0	5.2	10.3	6.0	11.4	...	...
10	5.2	10.7	6.1	12.2	8.4	18.4
30	5.0	10.0	6.1	14.2	7.5	19.4
45	5.0	11.0	6.1	17.8	8.6	21.3
60	5.0	10.7	5.7	15.6	8.3	22.7
75	4.9	11.3	5.6	14.7	8.4	21.7
90	4.7	10.0	5.4	14.3	8.0	22.7
105	4.7	9.7	...	...	8.3	21.7
120	4.8	9.4	...	...	8.1	23.4
			Sand No. 4			
0	5.0	10.7	5.1	14.3	...	...
10	5.2	12.2	5.6	16.2	...	...
30	5.1	10.3	5.1	15.2	...	...
45	4.7	10.0	5.6	17.0	...	...
60	4.5	9.4	5.4	15.7	...	...
75	4.2	7.7	5.4	15.2	...	...
90	4.0	7.0	4.8	15.2	...	...
105	3.9	7.5	5.3	17.0	...	...
120	3.7	6.0	4.8	15.7	...	...
			Sand No. 5			
0	4.5	34.0	5.3	36.0	6.7	34.0
10	4.5	33.0	5.3	31.0	5.9	35.0
30	4.2	31.0	5.5	31.0	6.4	38.0
45	3.8	30.0	5.4	31.0	6.8	40.0
60	3.6	30.0	5.6	33.0	7.1	36.0
75	3.6	29.0	5.3	34.0	6.8	36.0
90	3.5	29.0	5.4	36.0	...	...
105	3.5	30.0	5.2	36.0	6.3	34.0
120	3.5	27.0	5.3	38.0	6.3	29.0
0	8.5	26.0	10.3	31.0	...	...
10	8.1	38.0	9.8	36.0	...	...
30	8.0	40.0	9.5	40.0	...	...
45	7.9	40.0	9.1	40.0	...	...
60	8.0	36.0	9.0	40.0	...	...
75	8.0	38.0	9.0	36.0	...	...
90	7.6	38.0	...	...	...	...
105	7.5	38.0	...	...	...	...
120	7.4	38.0	...	...	...	...

(Continued on next page)

Table 6—(Continued)

Mulling Time Minutes	Water Per Cent	Permea-bility	Water Per Cent	Permea-bility	Water Per Cent	Permea-bility
			Sand No. 6			
0	4.6	24.2	6.1	42.0	8.0	36.0
10	4.5	24.2	6.0	36.0	7.9	55.0
30	4.3	24.0	6.2	36.0	7.6	54.0
45	4.3	24.0	6.3	31.0	7.4	54.0
60	4.2	24.2	6.2	36.0	7.2	58.0
75	4.3	24.2	6.1	36.0	7.1	62.0
90	4.2	21.8	6.0	40.0	7.1	62.0
105	3.8	21.8	5.6	34.0	7.3	62.0
120	3.8	21.0	6.3	44.0	7.2	59.0
			Sand No. 7			
0	5.4	46.0	7.4	46.0	7.8	42.0
10	5.6	50.0	7.4	40.0	8.1	44.0
30	5.4	56.0	7.1	48.0	8.3	46.0
45	5.6	63.0	6.8	56.0	8.5	48.0
60	5.2	63.0	6.9	54.0	8.4	52.0
75	5.3	63.0	7.0	56.0	8.3	52.0
90	...	...	...	...	...	...
105	...	...	...	...	...	...
120	5.8	44.0	6.9	42.0	7.8	42.0
			Sand No. 8			
0	...	...	....	...	...	...
10	5.9	44.0	6.8	42.0	7.5	38.0
30	6.0	42.0	6.6	36.0	7.2	36.0
45	5.9	44.0	6.4	44.0	7.0	38.0
60	5.8	47.0	6.5	58.0	7.6	44.0
75	5.8	52.0	6.7	52.0	7.7	44.0
90	5.8	58.0	6.2	62.0	7.7	47.0
105	5.8	52.0	6.5	55.0	7.6	42.0
120	5.8	62.0	7.0	49.0	7.5	38.0
			Sand No. 9			
0	5.2	36.0	6.7	40.0	8.9	42.0
10	4.9	34.0	6.6	42.0	8.6	49.0
30	4.6	30.0	6.5	42.0	8.2	52.0
45	4.6	33.0	6.6	44.0	8.1	57.0
60	4.9	40.0	6.6	44.0	8.1	64.0
75	4.7	38.0	6.4	52.0	8.0	52.0
90	4.7	36.0	6.0	52.0	7.5	58.0
105	4.8	38.0	5.7	52.0	7.6	62.0
120	4.6	34.0	6.2	52.0	7.5	62.0
	Sand No. 10				*Sand No. 11*	
0	6.2	49.0			8.0	39.0
10	6.1	47.0			8.1	40.0
30	6.0	47.0			7.6	49.0
45	6.1	52.0			7.5	55.0
60	6.0	52.0			7.6	55.0
75	6.0	52.0			6.5	55.0
90	5.9	52.0			6.6	55.0
105	5.8	52.0			6.6	55.0
120	5.8	52.0			7.2	55.0
			Sand No. 12			
0	5.2	40.0	6.7	38.0	7.2	42.0
10	5.0	44.0	...	42.0	6.5	42.0
30	4.9	46.0	6.2	44.0	6.8	44.0
45	4.9	46.0	5.9	47.0	6.6	44.0
60	5.0	50.0	5.9	47.0	6.8	47.0
75	4.9	50.0	5.8	49.0	6.9	49.0
90	5.1	54.0	...	....	6.5	44.0
105	4.9	52.0	...	....	6.6	47.0
120	4.6	48.0	...	....	7.0	49.0

(Concluded on next page)

Table 6—(Concluded)

Mulling Time Minutes	Water Per Cent	Permeability	Water Per Cent	Permeability	Water Per Cent	Permeability
			Sand No. 13			
0	4.4	146.0	5.8	90.0	8.0	70.0
10	4.1	128.0	5.6	93.0	8.1	74.0
30	4.4	116.0	5.5	100.0	8.2	78.0
45	3.8	102.0	5.2	105.0	7.9	80.0
60	4.2	108.0	5.0	119.0	7.8	84.0
75	3.9	124.0	5.6	110.0	8.0	84.0
90	3.8	151.0	5.8	110.0	8.3	80.0
105	3.7	151.0	6.1	116.0	8.1	83.0
120	...	.....	6.3	119.0	8.4	80.0
			Sand No. 14			
0	...	....	6.2	440.0	7.4	417.0
10	...	....	6.4	440.0	7.0	417.0
30	...	....	6.1	492.0	7.0	467.0
45	...	....	5.8	525.0	7.3	492.0
60	...	....	5.5	610.0	7.2	440.0
75	...	....	6.1	525.0	6.8	440.0
90	...	....	6.3	467.0	...	....

frees the voids of the material and thereby increases the permeability. If the water content of the sand being mulled is near the optimum, compound grains will form. These compound grains are composed of several or more grains bonded together by means of a matrix of clay. Such a formation of the compound grains will aid in increasing the permeability.

If a sand is mulled too dry there will not be sufficient water to bring all of the clay out of the voids even though by continued mulling some of it may be utilized. As a result compounding will not occur and the permeability will not increase very much, if any.

If a sand is mulled too wet the clay will interfere with the uniform mixing of the grains. Furthermore, it will form a sticky mass together with some sand grains and even though the permeability may rise with continued mulling it will not increase nearly as rapidly as when the proper amount of water is supplied the sand. If a sand possesses an average percentage of clay and has a small coarseness figure such as an Albany 00 sand, it should never be mulled too wet. If it is mulled when too wet the clay will form minute lumps which pick up small grains and silt. These resulting balls average from a thirty-second to a sixteenth of an inch in diameter and become hard with continued mulling. When these balls of clay form in a sand the sand becomes absolutely worthless if mulling is allowed to continue. The writer experimented with an Albany 00 sand which was mulled too wet and obtained a permeability of 26. The sand which yielded such a permeability contained many of the above described lumps. A photograph of these

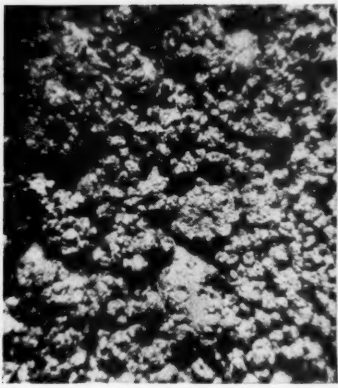

FIG. 7
SAND No. 3 CONTAINING 6 PER CENT WATER AFTER TEN MINUTES' MULLING

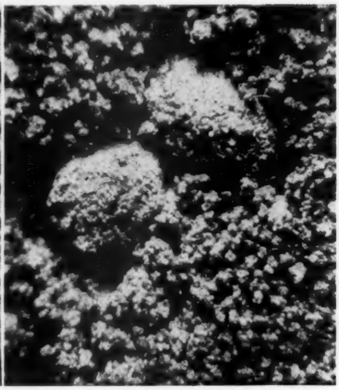

FIG. 8
SAND No. 3 CONTAINING 8 PER CENT WATER

lumps of clay and small sand grains interspersed in the sand is shown in Fig. 8. The sample which was photographed was taken directly from the muller. Fig. 7 is a photograph of an Albany 00 sand, containing approximately the right percentage of water. This sample was mulled for ten minutes. It can be observed that compounding of the grains has occurred in many cases and the sand is fairly uniform in distribution.

From the data of Table 6 points were taken for four of the sands and curves of permeability versus water content were plotted

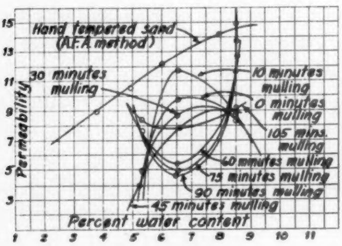

FIG. 9
PERMEABILITY VERSUS WATER CONTENT CURVE FOR SAND No. 2

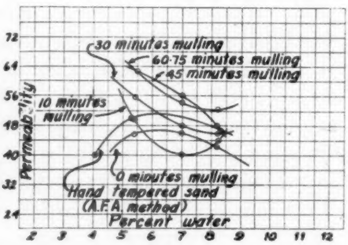

FIG. 10
PERMEABILITY VERSUS WATER CONTENT CURVE FOR SAND No. 7

for these four sands. Curves for the sands Nos. 2 and 7 are shown in Figs. 9 and 10.

Studying the first sheet of curves, for sand No. 2 (Fig. 9), which is a fine sand, there does not appear to be any fixed relation between the mulling time and the permeability. With this fine sand the permeability rises in all cases up to ten minutes' mulling. Past that point the permeability rises for water contents of 5 per cent and 8½ per cent, but in between these values the permeability shows quite a variation. This sand was in bags before it was mulled and as the contents of the bags was not mixed together it is possible that the sands in the bags were not uniform. When the sand was mulled one bag was used for each run. If the contents of the bags were not uniform as to the clay content or silt it is quite apparent that such a variation in the results obtained could exist. The curve for the hand-tempered sand shows a fairly uniform curve and is higher than the permeability values obtained from the mulled sands.

Sand No. 6 contains much less clay than sand No. 2 and is much coarser. As the mulling time progressed with sand No. 6 on Fig. 9 the permeability rose for values of water content above 5 per cent. Below this water content the permeability decreased slightly. This was possibly due to insufficient water being present to satisfy the needs of the clay in the sand.

Sand No. 7 of Fig. 10 is interesting in that the hand tempered sand gives a curve which shows higher permeability values than the sand mulled up to thirty minutes but lower permeability values than the sand mulled for more than thirty minutes. This hand tempered sand, as was explained on a previous page, was sand that had been mulled, tested, and allowed to dry out. It was then given the A. F. A. test for permeability.

Sand No. 12 (curve not shown), which is a fairly coarse sand, shows that the permeability rises, although not uniformly, as the mulling time progresses. The reason for the reverse curves is that the permeability did not increase uniformly with each water content. In connecting the points by means of a curve, a reverse curve had to be used.

The hand tempered sand in this case gave a curve which showed permeability values higher than the values obtained after

ten minutes' mulling, but values lower than the values obtained from mulling the sand for thirty minutes or more. This sand is a mixture of Milville Gravel and Albany-2 sand and to perform the hand test for permeability the mixture was made up as it was made for mulling. However, the sand tested by hand was not mulled. This sand, being a synthetic sand, could not be as uniformly mixed by hand as in the muller and for this reason we think the permeability curves of the hand tested sand occurs where it does.

In reviewing the permeability curves for the various sands it is very apparent that no strict rule is followed by the permeability

Table 7

SHOWING THE VALUES OBTAINED FOR THE SANDS LISTED FOR TENSION, COMPRESSION, AND PERMEABILITY TESTS, THE SANDS BEING HAND TEMPERED

Sand No.	Water Per Cent	Permeability	Tensile Strength	Compressive Strength
2	3.75	9.0	1.1	5.1
	6.0	12.2	1.1	6.4
	7.95	14.3	1.05	6.66
	9.7	20.0	1.1	6.4
3	4.0	10.7	.65	4.1
	5.3	12.6	.75	4.7
	6.5	11.2	.85	4.6
	9.0	10.7	.80	4.0
5	3.8	28.0	.45	2.7
	5.1	38.0	.65	5.4
	7.0	32.0	.45	3.2
6	4.2	33.0	.50	3.75
	5.8	47.0	.70	4.0
	7.0	42.0	.60	3.8
7	3.8	40.0	2.2	10.8
	5.3	49.0	2.55	11.8
	8.3	47.0	1.35	8.0
12	4.3	37.0	.40	3.9
	5.3	44.0	.90	4.3
	6.4	42.0	.70	3.8

of the sand as mulling takes place. In the case of the hand tempered sand, the permeability curve is generally a fairly uniform curve. When permeability curves are drawn for the sands, after they have been mulled for a time, no such uniformity of direction is seen. The slopes vary to a great extent and the resulting permeability curves no longer follow the general direction taken by the hand tested permeability plot. After examining the permeability curves for the various sands tested, the writer can find no relation between the jumps in the permeability curves, as mulling progresses and the time of mulling. It is true that mulling

increases the permeability of the sand, but this increase does not appear to follow any definite law.

Since the water content of the sand was not kept absolutely constant throughout each run but varied on either side of the desired water content, this may have had some effect on the permeability reading for each mulling time.

The main cause for the unsteadiness of the permeability curves, to the writer's mind, is that water was added from time to time to maintain the water per cent in the sand as near constant as possible. Suppose that the sand had been in the muller for twenty minutes. The water that was originally in the sand would have been worked into the sand for twenty minutes. Water that was added after the mulling was started would only have been worked into the sand for the time that it was present in the sand. Since water was added approximately every fifteen minutes it may be seen that this water that was continually being added may not have had sufficient opportunity to work itself into the sand before a sample was taken from the muller and consequently the permeability would be affected by this condition.

Distribution

The effect of mulling on the distribution and the compounding of the sand for different water contents may be studied by means of photo-micrographs which were taken of the sand as it was removed from the muller.

The first water content used was 4 per cent. This was too low to satisfy the complete demands of the entire clay content of the sand. In. Fig. 11 (sections marked 4 per cent water), may be seen this sand at 0, 10, 30, and 45 minutes' mulling. It is to be noticed in this series of pictures that uniformity of distribution is steadily made better as the mulling progresses. Some compounding occurs but not very much due to the low water content.

The next water content employed was 5.6 per cent water. Photographs (Fig. 11, sections marked 5.6 per cent of water) were taken of the sand at intervals of mulling, starting with zero minutes' mulling and going to one hundred and five minutes' mulling. This water content is near the optimum one for this sand. The distribution does not improve as rapidly as in the former case

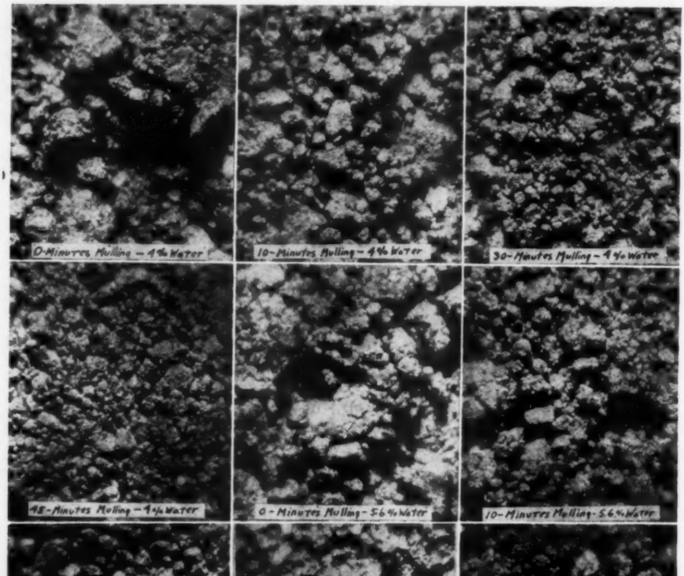

FIG. 11—SAND No. 13 CONTAINING 4 AND 5.6 PER CENT WATER SHOWINC CONDITION UNDER VARYING MULLING PERIODS

due to the increased plasticity of the clay in the sand. However, compounding occurs much more with this water content than with the previous one.

Two photographs were taken of sand containing 8 per cent water. One was taken at zero minutes' mulling and the other at thirty minutes' mulling. These two photographs may be seen in Fig. 12. It can be seen that this water content is too high for the sand as it does not become uniformly distributed but forms groups of grains into sticky masses.

The same sand was employed for all three runs with the different water contents. As a matter of interest and comparison it is interesting to compare the photographs of thirty minutes' mulling for each of the water contents. These photographs need no further discussion as they demonstrate clearly how mulling affects the sand when too much, too little, and the proper amount of water is employed.

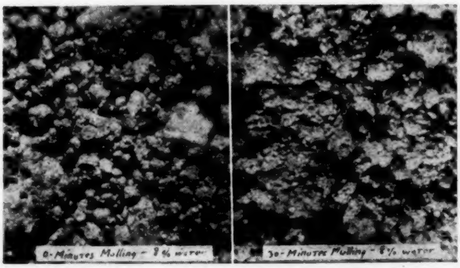

FIG. 12—SAND No. 13 CONTAINING 8 PER CENT WATER, PHOTOGRAPHED AFTER ZERO MULLING AND 30 MINUTES' MULLING

Coarseness of the Sand and the Clay Content

From examination of fineness test results of the sands mulled for the varying periods of time we found that for the coarser sands the coarseness figure rises slightly as the mulling progresses. This is simply due to some of the finer material being thrown out or becoming stuck to the sides of the muller. With the finer sands the increase in the coarseness figure is very small. The clay content also decreases slightly due to a small part of the clay being either thrown out or stuck to the sides of the muller.

The drier the sand, the more will be the increase in the coarseness figure, because the sand is not as heavy and also because the clay will not be as plastic and will not hold the sand together as it is thrown around. Therefore part of the finer material will break loose from the sand as it is thrown around and will be thrown out. The loss of this finer material is negligible in all cases, however.

Conclusions

In the great majority of cases, increasing the time of mulling the sand will increase the permeability of the sand.

With increased mulling the tensile and compressive strength of the sand will increase. Generally, the tensile strength will increase more rapidly with respect to the initial strength than the compressive strength.

The coarseness of the sand and the clay content will not vary to any great extent with prolonged mulling. However, if the sand is mulled too dry the decrease in fine material and clay will be more noticeable than when sufficient water is added to the sand.

It is more advantageous to mull the sand when the water content is slightly less than the optimum one. The sand should not be mulled when it is too wet.

With a fine sand, containing 15 per cent or more of clay, the sand should be mulled drier than a coarser sand of any clay content, not exceeding a workable amount of the colloidal substance. If such a fine sand is mulled too wet the sand will be ruined if the mulling is allowed to continue for more than ten or twenty minutes.

When synthetic sands are employed in a foundry the muller should be an indispensable piece of apparatus. It is the most efficient and rapid means of producing a good uniform mixture of the different sands employed.

Every foundry, if it is able, should have a battery of mullers, and if possible I would suggest that the floors where the most difficult work is done be put through the muller at least once every week or two weeks. New sand and also waste sand could be added to the heaps in this manner. This could be done at night when the night gang is cleaning up. Some of the floors could be put through the muller each night.

This report has attempted to show clearly just how mulling affects all types of sands. Sands ranging from fine to coarse were mulled and tested. In every case of a sand being tested the same results have been shown. In other words, the writer has conclusively shown that whatever type or quality of sand is being used it should be mulled at periodic intervals of time. The great increase in the strength of the sand and the rise in permeability are sufficient reward for installing and using a number of these mullers in the foundry. The writer would suggest that all fine sands be mulled for a period of fifteen minutes. However, if possible, longer mulling may be employed to good advantage. Medium coarse and coarse sands should be mulled at least ten minutes. For synthetic sands a longer mulling time than ten minutes should be used if possible. The writer realized that in many foundries even fifteen minutes' mulling could not be employed from the commercial side of the case. He would emphasize very strongly, however, that the sand be mulled even if it is for only a few minutes.

The filling and emptying of a muller necessitates additional labor, but this added cost will be greatly offset by the increased efficiency of the sand.

In concluding, the writer desires to call attention to the fact that all of the mulling tests described above were made in the smallest size muller. He believes the same results could be obtained in larger ones. Not having worked with a larger sized muller, the author cannot tell whether the results obtained would be gotten quicker or slower but it appears that the speed of the revolving parts of the machine determine the amount of gain made by the sand. Let it be stated once again and more emphatically that the added cost of maintaining and operating the mullers in a foundry will be greatly offset by the increase in the efficiency of the sand after being mulled.

The writer wishes to acknowledge the assistance of Prof. A. E. Wells for his many helpful and practical suggestions, and the direction of Dr. H. Ries under whom this research was conducted and who gave many helpful suggestions and constructive criticisms. He also wishes to thank the Goulds Pump and Manufacturing Company, the G. Pettinos Foundry Supply Company and the Paxton Foundry Supply Company for their kindly co-operation in sending different types of sands with which the writer worked.

Discussion

Major L. L. Anthes: Are very beneficial results found, as a rule, in mulling very fine sand?

A. V. Leun: As you mull the sand dry, you will get more beneficial results than if you mull it wet.

Major L. L. Anthes: Mulling has a beneficial effect on even fine sands?

A. V. Leun: Yes, if you keep it a little below the optimum water content.

Chairman R. A. Bull: What particular advantage do you find?

A. V. Leun: I find that in a fine sand the clay is very likely not to be well mixed in the sand. If it is mulled a little below the optimum water content, that clay, not being plastic, not having the correct amount of water to give it sufficient plasticity, will become mixed in your sand grains and then you can add the water and mull it a little longer and you will increase the strength greatly.

Chairman R. A. Bull: I would like to inquire if Mr. Leun has made any experiments to determine, and if he has found out that the mulling action in the case of those fine sands imparts any disadvantageous properties in the way of pulverizing the grains and increasing the fineness beyond the desired point.

A. V. Leun: I ran a series of coarseness figures on several sands, in fact, I ran 246 fineness tests in all, and I found that very little change was evident in the average grain size and in the clay content.

R. F. Harrington: Mr. Leun, have you any record of the permeability and the compression strength between the period of zero and ten minutes?

A. V. Leun: I did not record the permeability between those points. I started to but I found that I would never get through my investigation because I wanted to carry it up to 120 minutes.

R. F. Harrington: My point in asking that question is because, from the practical standpoint of handling the sand, we are pretty much interested in that period around a minute or two or three minutes.

Chairman R. A. Bull: Mr. Harrington's question is important, I think. The foundryman is concerned with the practical periods of time he can employ in regular operations, and I hope Mr. Leun can continue his experiments within what we might term the working range as to the time practical to use in regular molding. Perhaps, offhand, from zero to 25 or 30 minutes, which might be fairly practical. Mr. Harrington, have you had the opportunity to make any definite determinations that you would like to tell us about?

R. F. HARRINGTON: Mr. Chairman, I can't recall the figures, the attempts were made so long ago, but my recollection of them is that they found at the period of three minutes there was quite a marked decrease in permeability, which had to be offset by aerating the sand through some sort of a belt aerator. But, further than that, a point that I might suggest is the question of flow of that sand. That is a problem that concerns us in the foundry, because unless that sand has been mulled to the extent of gaining a marked increase in compression as further aerated, it doesn't handle well in the foundry when you are filling your mold by some mechanical means of filling, and we don't get the flow of the sand around the pattern.

A. V. LEUN: Mr. Harrington, did you find that if you mulled the sand a little below the optimum water content you wouldn't get the caking up that you referred to, that it would flow a lot better and you could still maintain your pretty high strength?

R. F. HARRINGTON: I might answer that by saying that you might mull the sand a little bit below the optimum water content but when you realize that that sand has to remain in the foundry and spend maybe 15 minutes in transit from one position in the foundry to another, and then remain in the foundry for another 6 or 8 hours, you have to keep the water content pretty well up in order that it doesn't become too dry to handle in the foundry. So we are always confronted with the practical aspect of the thing, which is to get the water content sufficiently high so as to make a workable sand. That is the reason we can't always mull the sand at the water content that might be most desirable from the standpoint of the immediate test that you might make on that sand on permeability.

CHAIRMAN R. A. BULL: I am in pretty close contact with a good many foundry foremen, and, without attempting in the slightest degree to detract from the value of papers employing these scientific terms, I think it is distinctly worth while in the verbal presentation of these papers for us to remember that there are many men of very, very valuable experience, men on whom we must depend finally to apply these more scientific methods that we are advocating, who would wonder what 120 minutes' time has to do in a consideration of the subject of mixing molding sands in the foundry.

When we put a lot of things into a pan muller, or any other kind of a mixer, to make them thoroughly distributed, there are a good many considerations that are highly important in the casting of metals that are materially improved if we prolong the mixing operation within a reasonable limit that can be used in any foundry. Several foundries with which I am associated determined quite definitely the valuable effect in making steel molding sand mixtures of a definitely regulated time, sufficiently long, as the result of tests, to give the properties in the mixture that we wanted to get, and which were desirable for making the product. I think in

foundries of that particular kind several years ago it was quite the common practice to use two or three minutes in whatever type of pan muller they happened to employ. But I am quite sure now that that time ought to be extended to from 7 to 10 minutes, depending somewhat on the speed of the muller or the speed of the revolving pan, whichever type may be employed, and also on the condition of the mixer. I think it might not be out of place to emphasize that point, that no mixer is worth a continental unless the plows are in good shape and unless the mullers themselves are in good condition.

It is, I think, an excellent procedure to have a systematic method of maintaining the proper condition of all sand mixers, the nature of which is such as to cause continually a large amount of wear. It is considerations like that that we must keep in mind, as practical men, when we are trying to apply information that is developed in an experimental way. In other words, that prolonged mixing time which we might employ as the result of experiments will not do us the good that we expect it to do unless that equipment is kept in good shape.

C. A. Hansen: There is a good deal of indication that optimum, which, according to your dictionary, means best, is by no manner of means best in the sense that should have been conveyed by the term. We tested sands at various moistures. All of us I think more or less generally jumped to the conclusion that that particular combination of conditions which led to maximum green strength led to the most usable sand; but, as a matter of fact, it does not. This was discussed more or less at length in the paper I gave a day or two ago.

A. V. Leun: I would like to remind Mr. Hansen that I ran these experiments primarily to show the foundryman how a fine sand, a coarse sand and an intermediate sand would react in the muller and what advantages you could get out of it. I did not run them to show any other result; I merely ran them to show how they were affected and tried to explain why they were so affected.

G. Olson: Talking about mulling sand, there has been nothing said so far about the speed of the muller nor the weight of the muller nor the type. Now, I would like to ask of Mr. Leun whether he uses a suspended muller or one that rides on the bottom. If the latter case, the weight of the muller and the speed also are very important. What I have in mind is what we were doing some 20 years ago in the country where I came from. We were mixing all our facing sand in a muller the weight of which was 375 pounds. We were using two mullers of about 375 pound weight and running about 30 or 32 revolutions per minute. We put the sand through those mullers for 7 or 8 minutes, after which time we took it out and ran it through an aerator, and we had the best facing that I have seen made. But, of course, as I said, emphasis must be laid upon the weight of the muller and the speed in order to get a correct figure as

to what result we will get. We may run a muller with 200 pounds weight at 40 revolutions or 80 revolutions or any number at all, yet we cannot tell anyone who hasn't any practical experience with it what it will do for him in his particular case. So I would like to ask Mr. Leun what he used.

A. V. Leun: So far as telling the weight of the muller, I mentioned in my paper that it was a Simpson No. 0 muller. I also said I didn't know how this would affect the results I obtained, whether they would be affected in a shorter or longer period of time by using a larger type muller.

So far as naming the weight, I didn't think that was necessary, because I specified the make I was using.

G. Olson: If the Simpson muller is used, I would say the weight wouldn't make so very much difference. Then, the load of sand is more important than the weight of the muller, because if you use a certain sized muller of the Simpson type, say a No. 0 or No. 1 or whatever you use, your load is the determining factor there as to the ultimate results. What I mean by this is, if you use a No. 1 Simpson Mixer and you put in the correct load, that they specify, then we all know what we ought to expect, but suppose you put in only half the amount of sand, you are not going to get the mulling effect that you would if you had the full amount of sand in.

R. F. Harrington: Mr. Chairman, first of all I want to congratulate Mr. Leun on the work that he has done. I think that it is a very effective piece of work. I think that we are going to take this home and look it over more carefully and get a great deal out of it. I have commended for his consideration the question of times between zero and five or ten minutes, and now I would commend for his consideration the question of the effect on permeability, compression and tensile strength when the sands contain a higher percentage of moisture, my thought being along Mr. Hansen's line, that it is essential sometimes, for example, we find it to advantage to use a moisture content as high as 8.7, we probably figure on 8.5 of moisture on those coarser sands, the reason for that being to absorb the lead and take the lead on the edge of the mold more easily than if we had a lower moisture content. Furthermore, we developed what Mr. Dietert spoke about the other day and increased dry sand strength, which is essential, and I think that this work that Mr. Leun has done could be made very, very much worth while and throw a good deal of light on this if he carried his moisture contents up a little higher so that those of us who have to use higher moisture contents from the practical standpoint could get a line on this question of mulling.

E. S. Carman: In regard to the question which Mr. Harrington has raised, I believe there is a great field for what he says for immediate application to foundry problems.

Regarding this question of time of mulling in order to apply the mulling of sand to the practical use of the foundryman at the present time, that is a good thing, a very good thing indeed, and we should have knowledge along that line. But let me just suggest this, that as I understand the purpose of the paper just presented, it was to find out the characteristics of sand in regard to the length of time of mulling. Now, after all, what the committee of the American Foundrymen's Association is after is to make progress in the handling of sand. Therefore, I think that a paper similar to this is very fitting and proper, because it points out clearly what we ought to do in order to have a better sand.

Now, then, suppose it is ten years ahead of the practical application. Well and good. What is necessary? We must, then, have a means of mulling sand that will give a strength equal to that given by 120 minutes of mulling time in one or two minutes' time. Therefore, I believe this brings out the fact that what we need is a study of equipment, really, that will give the foundryman the sand that he ought to have with a very minimum amount of time of mulling, in order that it may be practical.

CHAIRMAN R. A. BULL: Mr. Carman, as an engineer, has his mind busy now trying to attempt something, which reminds me of the speaker's remarks at the banquet last night. I am sure he will find all the foundrymen disposed to cooperate very heartily in efforts to develop improved processes of mixing.

Practical and Technical Data Obtained From the Use of Clay Bond in Molding Sand Heaps[1]

By R. F. Harrington,[2] A. S. Wright,[3] and M. A. Hosmer,[4] Boston, Mass.

The company with which the writers are associated has, for a great many years, given serious consideration to the question of sand conservation, reclamation and control. A review of the records of the technical department, under whose direction conservation and reclamation problems come, shows that in the years 1915, 1916 and 1917 many attempts were made to employ clay as a binder in our molding sand heaps. The records indicate considerable success for a short period of time. On the other hand, serious difficulties cropped up after the bonding material was employed for a longer period of time and apparently the difficulties were insurmountable with the knowledge of sand then at hand.

Recent Research Aids New Investigations

Since that time the Joint Committee on Molding Sand Research of the A. F. A. has been formed and has functioned both from the standpoint of the development of standard testing methods and investigation of conservation and reclamation. This has resulted in greater interest throughout the country in sand control and conservation, as evinced by the excellent results submitted in the papers before the American Foundrymen's Association meetings in recent years. Standard methods have allowed for an interchange of data which was not formerly possible.

Again with the feeling that possibly previous failure in the case of clay bond had been due to lack of scientific knowledge pertaining to sand, it was not unusual then that this company,

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[1] Presented on behalf of the New England Foundrymen's Association.

[2], [3], [4] Metallurgist, assistant metallurgist and chemist, respectively, The Hunt-Spiller Mfg. Corp.

which for many years has been attempting to reduce new material consumption because of high initial sand costs, should again renew its efforts to make use of a clay bond to that effect.

Previous efforts at this plant had been along conservation lines through the use of more intensive mixing equipment, the results of these investigations having been incorporated in papers prepared for other occasions.

In March and April of the year 1925 exhaustive tests were being made with ordinary high quality Jersey clays. Clays employed, however, were not proved clays in the sense that they had been employed with any particular success, at least to the knowledge of the authors. In the early part of this investigation there came to the attention of the foundry and metallurgical department a well-known clay bond which, from authoritative sources, showed considerable success in a number of eastern plants. This material was presumably an especially prepared clay and because of the satisfactory results reported, it was decided to abandon the tests with the untried clays and employ the better known product.

Scope of Paper

The writers will endeavor in this paper to cover from a very practical standpoint the many problems which were encountered in an effort to successfully employ this material in molding sand heaps. Throughout the entire period of investigation and research, quality and appearance of castings were held to be first or paramount and economy of sand second. Of course the rebonding of molding sand heaps by the addition of a clay is not a new problem, as this is common practice in the case of steel foundries and is to a small degree the practice in the gray iron foundry.

In the tables that follow reports are given as to the condition of the casting, both in the cleaning room and in the machine shop. Reference to condition in the cleaning room refers to general appearance of the casting, ease of cleaning, etc. In the case of the machine shop, the report refers to the condition of the casting after ⅛ inch has been machined from the surface of

the casting and refers particularly to sand inclusions, or inclusions of material from the surface of the mold which occurred directly beneath the skin of the casting.

Fully realizing that no arbitrary standard can be made without knowledge of the practical working of the sand, permeability and strength tests, with all other factors, were in every instance correlated with the practical aspects of the sand.

Mulling Found Desirable

The first attempts to employ the clay bond were made with the addition of the clay into the heaps only by means of hand mixing and screening. As high as 5 to 10 per cent of clay bond was employed in this respect, but the sand was clearly not of such a character as to be workable. A further test of only two or three days was required to indicate the desirability of mulling the heaps at least until such time as the clay was thoroughly incorporated, and thus became the basis for further additions.

The castings selected for the first test were approximately 150 pounds in weight, cylindrical in character and of 1⅛-inch section. The first two castings produced when the muller was employed were excellent castings in every respect. In this instance 91 per cent of old sand and seacoal was employed with 9 per cent of clay bond. This mixture showed remarkably high strength tests, and, therefore, the muller was discontinued in the belief that having once incorporated the clay thoroughly it might be possible to incorporate smaller additions by means of the hand mixing method.

Thereafter mixtures employed approximately 97 per cent of old sand and seacoal, the balance being composed of clay, as indicated in Table 1.

Excellent castings were produced under these conditions, at least so far as machine shop reports were concerned, every casting showing satisfactory after ⅛ inch had been removed for finish. The castings, however, were considerably rougher in outside appearance than those produced under regular operation. Therefore, seacoal was added at this time in somewhat greater quantity.

Second Series of Tests Used Greater Per Cent of Seacoal

The next series of tests, involving fourteen castings, as illustrated in Table 2, employ a larger percentage of seacoal with clay bond varying from 2½ to 3½ per cent. Here again the sand was mixed entirely by hand—that is to say, shovel mixed and screened. The permeability tests showed definite tendencies toward lower levels, and similar conditions existed in the case of the cohesiveness test and per cent clay present.

Here we have two conditions, it is believed, contributing toward the very unsatisfactory showing that was made. An

Table 1

Per Cent Old Sand	Per Cent Clay Bond	Per Cent Sea-Coal	Permeability Number	Cohesiveness Number	Per Cent Moisture	Per Cent Clay	Mixing Method
89	9	2	138	282	7.2	15.9	muller
95	3	2	146	175	7.4	12.4	hand
95	3	2	156	188	7.5	14.0	hand
95	3	2	173	196	7.6	13.0	hand

Table 2

Per Cent Old Sand	Per Cent Clay Bond	Per Cent Sea-Coal	Permeability Number	Cohesiveness Number	Per Cent Moisture	Per Cent Clay	Number Castings Made
88½	2½	9	75	179	7.8	11.4	2*
96	2½	1½	108	169	8.0	11.8	2*
97½	2½	0	138	142	8.2	10.3	2*
95	5	0	142	145	8.2	11.0	2*
96½	3½	0	115	170	8.5	11.0	2*
96½	3½	0	119	195	7.9	11.7	2*
96½	3½	0	115	183	8.6	13.0	2*

Machine Shop Report: * 2 poor or rejected.

excess of moisture present for the low percentage of clay with consequent reduction in permeability and a fictitious strength or cohesiveness that was incapable of producing satisfactory castings. It is quite evident that the low permeability of 75 was brought about through the immediate introduction of seacoal to a large extent, which was added for the purpose of obtaining smoother and more satisfactory castings.

This was followed by a reduction in seacoal, and as indicated by Table 2, an entire elimination of seacoal for the balance of time involved. It is to be noted that there were fourteen castings reported as poor or rejected by the machine shop.

Objections to Increasing Clay Content

One might well ask the question, "Why, if the clay content is low, was there not more clay added?" This would be a perfectly logical question and can only be answered by stating that the clay content could not be increased by greater additions without a further reduction in permeability. That is to say, the clay by the mixing operation as employed was incapable of being properly incorporated around the sand grains.

It is our belief that the large number of poor castings produced was due to a lack of proper strength in the sand. This, we believe, to have been a factor more important even than the permeability. To be sure in the last two instances we have a cohesiveness of 195 and 183, which under ordinary circumstances would indicate a sufficiently strong sand, yet a condition of weakness actually existed as measured by the usual foundry standards of feel, etc. It is unfortunate that occasionally the tests do not apparently detect the true conditions.

The authors have after very exhaustive tests come to the conclusion that permeabilities in excess of 115 for this class of work are desirable, although, as we have stated, we believe the cause of defective castings in this instance was lack of strength. The sand apparently did not have sufficient strength to withstand the action of the metal in the mold. It is to be understood that in all instances the sand referred to is a green sand mixture.

Importance of Venting

The authors at this time, in connection with permeability, have thought it desirable to mention certain experiences wherein mold permeability, or ability to conduct the gases away from the mold, play an important part in the production of good castings. A sand of the following characteristics was employed in the test and the test was based upon the theory that an unvented flask produced a condition within the mold that prevented proper escape of gases, and, therefore, the group of castings were made from the same sand both in vented and unvented flasks. The characteristics of the sand follow:

Permeability,	190 average.
Cohesiveness,	190 average.
Moisture,	8.2 per cent.
Clay,	13 per cent.

The test involves fifty-two castings in each case.

The machine shop reported in the case of the unvented flask, 78.8 per cent good castings and 21.2 per cent of the castings containing sand inclusions.

In the case of the well vented flask, and by this we mean a flask having 3.6 per cent of its surface vented, the machine shop report 92 per cent good castings and 8 per cent containing slight sand inclusions.

Our belief in reference to the trapping of the sand by the metal in the unvented flask is that the gases which are given off within the body of the mold have no outlet except at the joint. There being a large volume of sand involved between the joints, the gases seek the lines of least resistance, which is to the mold void. This escape of the gases in this direction we believe takes particles of sand and graphite facing from the mold surface. These are engulfed by the rising metal and are thrown toward the mold walls, later to be found beneath the skin of the casting upon machining. This condition was frequently observed in open molds and we believe the theory has been proved conclusively that the unvented flask is a hazard not only as indicated by the results tabulated above, but proved many times in addition.

It is noted that the permeability of the sand used in the test involving the vented and unvented flask is relatively high and it is the writers' opinion that with the low permeability prevailing in the use of clay bonded heaps, the vented flask is even more essential. All flasks throughout the entire shop were vented after this test. It is the belief that the thorough venting of the flask has to some extent assisted in the problem of mold permeability or the ability to carry away gases contained within the mold without excessive venting on the part of the molder and thus indirectly assisted in the use of clay bond.

Obtaining Desired Strength of Sand

As a consequence of the writers' belief that a higher clay was needed, the next step was to employ a sand of higher clay content which would insure greater strength and a means of mixing which would insure greater blending of the different ingredients with consequent elimination of the tendency toward a low strength sand. Table 3 shows the mixture of sand employed, together with the physical tests obtained and the machine shop report pertaining to these castings.

In the case of the series of castings of Table 3, it is to be noted that a higher clay content is employed. This is in line with the desired change involving higher clay content sands.

Table 3

A. F. A. TEST

Mixture—By Volume			A. F. A. Tests Report				Number
Per Cent Old Sand	Per Cent Clay Bond	Per Cent Sea-Coal	Permeability Number	Cohesiveness Number	Per Cent Moisture	Per Cent Clay	Castings Made
95¼	4¾	0	142	270	7.7	16.7	2*
96¾	0	3¼	124	238	7.1	17.0	2*
90¾	3	6¼	122	290	7.5	17.0	2*
98¼	1¾	0	160	236	7.8	16.6	2§
96¾	3¼	0	151	249	7.5	14.5	2*
96¾	3¼	0	171	235	6.9	14.8	2*
96¾	3¼	0	161	235	7.5	15.4	2*
98¼	1¾	0	146	268	8.2	17.3	2*
98¼	1¾	0	161	266	8.1	17.6	2†
95¼	1½	3¼	125	242	8.3	17.2	2‡
97	1½	1½	138	248	8.1	16.0	2†
97	1½	1½	107	246	8.1	15.9	2*
97	1½	1½	105	242	7.8	16.4	2*
98¼	0	1¾	112	255	7.2	16.4	2*
97	1½	1½	110	235	7.5	14.4	2*

Machine Shop Report: * 2 satisfactory; § 1 fair and 1 satisfactory; † 1 satisfactory; ‡ 1 satisfactory and 1 passable.

Furthermore, the muller type of mixing unit had its effect in producing a better blending of the clay and old sand with its seacoal quota, with a consequent increase in the strength of the sand, likewise a reasonably high permeability in the face of a higher clay content, was obtained.

The theory in connection with the muller has been that the mulling action so coats the various grains of old sand with the clay that the clay is removed from the voids, thus not only gaining strength, but maintaining relatively satisfactory permeabilities. In the case of other means of mixing, especially where

clay is added in the raw state, and especially in sands with relatively high clay content, the clay seems to remain between the voids, thus limiting the extent to which clay can be added because of its effect on reducing permeability.

That the ground for belief that a high strength sand was needed in connection with the castings, as illustrated in Table 2, was correct, seems to be borne out by the excellent results obtained in the castings illustrated in Table 3.

Satisfactory results having continued on the small class of castings, i. e., on castings weighing 100 to 150 pounds, this part of the shop was put over on a production basis until all of the castings of this class, involving some 100 to 200 in number, were made with sand employing clay bond as part of the mixture to the extent of 1 to 2 per cent. From time to time poor castings were obtained and the physical properties of the heaps had to be watched closely, especially for strength and permeability.

Mechanical Mixing and Handling Problems

The amount of seacoal, or character of seacoal as to fineness, in the sand, was another troublesome factor. At one time the loading of sand from the muller into the transfer bucket was a cause of uneven mixing of material with its consequent effect. The sand as it was discharged from the muller fell into the boot of a bucket conveyor which elevated the sand to a point at which it could be discharged into buckets for transference down the length of the foundry. As the sand fell from the chute into the bucket a cone was formed of very fine material, the pebbles or coarse material collecting at the outer edges. As the basis of this sand is a very coarse material of the nature of Millville gravel, this separation becomes of serious moment. This happened in spite of the fact that the sand had all passed through a ¼-inch mesh sieve as received from the producer. Mention of this is made merely for the purpose of indicating some of the difficulties that may occur in the handling of sand of this character. The result, so far as castings were concerned, was that the separation at this point caused coarse material to frequently

come in contact with the pattern with consequent rough castings. This condition was aggravated by the fact that the molds are not faced, the entire heap being of facing quality.

As the work progressed it became evident that beyond a certain point it was next to impossible to increase the permeability of the sand where the muller was used as a mixing unit. This applied particularly to the heavier types of castings when the entire shop went over onto a production basis. However, it was found that a sand aerator of the belt type could be used with the muller and that this machine would open up the sand to an effective degree. Accordingly all sand after coming through the muller was put through the aerating unit. The result is seen in Table 4.

Table 4

	Before Passing Through Aerator			After Passing Through Aerator		
Sand Number	Per Cent Moisture	Permeability Number	Cohesiveness or Bond Test	Per Cent Moisture	Permeability Number	Cohesiveness or Bond Test
1	8.25	126	250	8.2	140	228
2	7.50	140	228	7.5	165	208
3	8.8	127	223	8.78	156	203

Proper Jolt Ramming Important

At this time the records show the serious effect of improper jolting. In one day, for example, where the number of jolts was increased 20 per cent over that considered standard, we had 66 per cent rejected castings because of scabs on one particular floor. Resuming the standard number of jolts, 100 per cent perfect castings were obtained. It is barely possible that in the early stages of clay bond additions the heaps were frequently on what one might term "the ragged edge," thus it was easy to throw them out of balance either from the standpoint of the sand itself or by slight deviations from standard manipulation in the foundry.

We continued making approximately thirty castings per day of this type for some few weeks, gradually increasing, however, the amount of work made with clay bond material on some of the other floors. This was planned in order to have a sufficient number of heaps and a sufficient tonnage of sand actually

in production to observe any operating difficulties that invariably occur.

Experiments With Paddle Type of Mixer

As the use of clay bond became more and more extensive, the problem of a mixing unit began to present itself. Although machinery for loading and discharging the muller had been installed, it was not possible to further increase the amount of work handled by the one unit to take care of any further extension of clay bond in the heap. It was therefore thought desirable to try mixing some of this material in a paddle type of mixer which was available. A few castings were made each day with sand mixtures and results as indicated in Table 5.

Table 5

Mixture—By Volume			A. F. A. Tests Report				Number
Per Cent Old Sand	Per Cent Clay Bond	Per Cent Sea-Coal	Permeability Number	Cohesiveness Number	Per Cent Moisture	Per Cent Clay	Castings Made
94	5	1	201	219	9.1	16.6	1*
94	5	1	201	214	9.0	16.9	5*
94	5	1	215	217	8.8	16.4	5*
94	5	1	198	243	8.8	18.2	5*
94	5	1	173	238	8.9	18.6	5*
95½	3	1½	185	236	8.8	18.0	5*
95½	3	1½	205	214	8.7	15.1	5*
95½	3	1½	198	222	8.7	17.3	5*
95½	3	1½	178	216	8.5	18.1	10*
95½	3	1½	156	214	8.7	16.2	20*

Condition in Cleaning Room: *Satisfactory.

A study of Table 5 reveals higher permeabilities and slightly lower cohesiveness values than was obtained by use of the muller and aerator machine. The unusually high clay content was employed in order to insure high strength by this means of mixing. It was early recognized that the method was capable of producing higher strengths than anticipated and, therefore, the clay was immediately cut to 3 per cent and ultimately to approximately 1½ per cent, with satisfactory strength tests. The sand in this case was not put through the aerator, as the permeability obtained directly was sufficiently high in itself. As the table shows, the castings were good and this method of mixing was apparently satisfactory.

Preventing Scabbed Castings

At this point in the investigative work, in those heaps that had been put over onto a productive basis, scabby castings were more or less frequently encountered. This character of defect proved extremely difficult to overcome. Relief was sought in sands of greater strength and of greater permeability, but apparently it was impossible to entirely avoid the tendency for scabbed castings, particularly in certain classes of work, in spite of physical tests that apparently should give sand satisfactory and capable of producing good castings. It is to be appreciated that there had been no new sand added to these various heaps since the inauguration of clay additions which, at this time, involved a period of some two or three months. We were not free from this character of defect until replenishment of the heaps with a certain percentage of new sand, and here apparently the small percentage of new sand, varying from 4 to 8 per cent, was sufficient to produce within the sand characteristics which eliminated to a very great extent the tendency toward scabbed castings.

More or less experimental work in connection with clay bond as a partial substitute for molding sand had now been carried on for a period of approximately five months. The work had passed through the stages of one or two castings per day basis on one floor to dozens of castings per day on three or four floors. The method of mixing, as indicated, had been changed so as to meet additional requirement and the properties of the various heaps and condition of the resulting castings had been closely observed.

Use of Sand Cutter

Before the advent of clay bond there had been added a certain percentage of new sand to the molding sand heaps each night, the percentage varying with the character of the work. The process of mixing consisted of the distribution of the new sand and its seacoal quota through the heaps, followed by the mixing operation which consisted of running the sand cutter through the heaps three times with consequent screening through

a 1-inch screen. This process is not described in further detail because it is felt that the process is generally familiar to all foundrymen.

This method of mixing when used in connection with percentages of new sand varying from 20 to 35 per cent, seemed to be quite satisfactory from a mixing standpoint, although the mixing was not sufficient to rid the heaps of all evidence of new sand. The method, as is well recognized, resulted in a very low sand handling cost. We had tried this method of mixing the clay bond with the heaps for a few days during the early investigative work. It seemed impossible to gain the desired strength and, therefore, as has been stated earlier in the paper, the process was abandoned. However, when the time came to further increase the use of clay bond and the capacity of both the paddle wheel type of mixer and the muller type of mixer had been reached, the problem of sand handling became very acute. This was not only in connection with the purchase of new mixing equipment, but also with the amount of handling which was increased to a considerable extent due to the necessity of bringing the old sand to a central mixing plant. This was in contrast to the former practice of bringing the new material to the molding floors where it was mixed, as previously described.

The interference with crane operation, both when cranes were handling metal and assisting molding operations, was of serious consequence. In fact, this interference, because of the large tonnage of sand involved, made any attempt to utilize the central mixing idea almost prohibitive.

With the desire to extend the use of clay bond, we were, therefore, faced with the necessity for other means of mixing. For this reason we resorted again to the sand cutter method, although as has been indicated the muller and the paddle wheel type of mixer were doing their work well.

A careful study of the possibilities of the sand cutter resulted in the feeling that with more care in the distribution of the new material, together with an increased number of cuttings, it could be made a success. The number of cuttings was in-

creased to eleven, and with this added cutting, and the attention to other details, we were successful in introducing the clay bond plus the small percentage of new material to the extent of 4 to 8 per cent.

The physical properties of the heaps were readily maintained, as evinced by Table 6.

Table 6

SAND MIXED BY THE AUTO SAND CUTTER

Mixture—Per Cent, by Volume					Physical Properties				
Sand Old	New Sand	Clay Bond	Sea-Coal	Fire Sand	Permeability Number	Cohesiveness Number	Compression	Per Cent Moisture	Per Cent Clay Content
88½	8	2	1½	0	193	196	....	8.4	13.6
88½	8	2	1½	0	178	198	8.38	8.4	14.5
88½	8	2	1½	0	163	190	8.00	8.3	14.2
88½	8	2	1½	0	163	198	8.13	8.1	14.8
88½	8	2	1½	0	156	190	6.75	8.1	13.6
88½	8	2	1½	0	151	191	7.13	8.1	13.6
88½	8	2	1½	0	151	184	7.00	8.1	13.9
88½	6	2	1½	2	156	192	7.25	7.8	14.8
88½	6	2	1½	2	151	186	8.38	7.7	14.6
88½	6	2	1½	2	163	184	....	8.0	14.3
88½	6	2	1½	2	146	...	7.13	7.5	14.0
88½	6	2	1½	2	163	184	7.56	8.0	14.3

Control Testing Methods Important

The laboratory in the meantime had definitely determined that the compression test offered a better means of checking the strength characteristics of the heap, and consequently it was substituted for the cohesiveness or bond test as a routine control check on the sand. The compression values are included in Table 6 as well as the cohesiveness or bond test.

Maintaining Permeability When Using Sand Cutter

The sand as produced by the sand cutter was not as high in permeability as was anticipated, although satisfactory castings were obtained. An attempt was made after the seventh day to increase the permeability by the addition of 2 per cent of fire sand. A study of the results in Table 6 indicates no change in permeability with a slight decrease in cohesiveness. Consequently fire sand was taken out of the mixture in order to maintain the required strength.

The percentage of clay bond was kept at 2 per cent and during the course of the next few weeks lower permeabilities were encountered with increasing clay content. It was very apparent that 2 per cent of clay was more than was needed to maintain the proper strength. Clay bond was consequently left out of the mixtures for a few days and then added at the rate of 1½ per cent per day. The same results were obtained using this percentage but it took a longer period to develop. After much experimenting the clay bond was dropped as low as ½ of 1 per cent. It was found, however, that the heaps were below the required strength. At the present time ¾ of 1 per cent is giving very good results. This is apparently the percentage best suited for the work and is capable of being distributed through the heaps by the sand cutter method of mixing.

Although the physical properties of the sand were unchanged, periods came (perhaps only every month or so) when it was necessary because of excess cutting, to give the heaps an appreciable "shot" of new sand. This amounted to usually about 30 per cent and was kept up for only one day. It has thus far been impossible to detect this condition except by close examination of the castings made from the heap, and we are unable at this time to suggest what the new sand does or what remedy outside of new sand can be used.

Dry Sand Work

Up to this time no mention has been made of work other than green sand and as the use of clay bond had been extended to castings made in dry sand, it is interesting to study the progress of clay bond in this connection.

The heap itself had always been a mulled sand so the method of mixing has not changed to this date. Table 7 shows the progress of this heap from the time clay bond was started until the present time. Group A includes the mixture previous to the use of clay bond. The table further shows mixtures and conditions of heaps as measured by the A. F. A. tests and is composed of four representative days selected at approximately one month intervals.

A study of Table 7 reveals several interesting features when results obtained on heaps having clay bond additions are compared to those in which new and old sand only is employed. These features are:

(1) Lower, although uniform, permeability with varying amounts of clay bond.

(2) Generally lower compression values, with apparent inability to develop strength with increased clay content as might theoretically be assumed.

Table 7

	Mixture—Per Cent, by Volume				Physical Properties				
Group	Old Sand	New Sand	Clay Bond	Fire Sand	Permeability Number	Compression Test	Per Cent Moisture	Clay Content	Dye Adsorption
A	62	38	...	...	347	8.25	7.7	12.4	500
A	62	38	...	...	345	7.90	7.7	12.1	508
A	62	38	...	...	359	7.75	7.6	10.8	504
A	62	38	...	...	332	8.44	7.9	12.0	516
A	62	38	...	...	346	7.64	7.9	11.6	472
B	78½	18½	3	...	341	7.13	7.7	13.0	540
B	80	9¼	1½	9¼	300	6.50	7.9	13.2	472
B	80	13¾	...	4¾	275	6.50	7.7	13.0	464
B	80	13¾	...	4¾	287	6.38	7.4	13.4	424
C	80	13¾	1½	4¾	253	6.50	7.1	14.1	400
C	80	13¾	1½	4¾	253	6.50	7.1	14.1	400
C	80	13¾	1½	4¾	275	6.13	7.2	14.4	408
C	80	13¾	1½	4¾	264	6.38	7.4	13.8	384
C	80	13¾	1½	4¾	287	6.00	7.1	14.6	408
D	80	13¾	1½	4¾	264	7.25	7.5	15.7	424
D	80	13¾	1½	4¾	275	7.33	7.4	15.6	444
D	80	13¾	1½	4¾	287	8.17	7.5	16.5	416
D	80	13¾	1½	4¾	248	8.00	7.5	15.7	412
E	80	14¼	¾	5	326	6.63	7.0	13.5	368
E	80	14¼	¾	5	306	6.63	7.1	13.9	384
E	80	14¼	¾	5	275	6.50	7.1	13.4	412
E	80	14¼	¾	5	275	6.54	7.1	13.5	408

(3) Lower moistures varying with different percentages of clay, as shown in groups C, D and E. The moisture present was low in relation to the clay present.

(4) Increasing clay content from 11½ per cent in group A to 16 per cent in group D, and a decrease to 13½ per cent in group E when clay bond per cent was reduced in the heap.

(5) Decrease in dye adsorption with increased clay content showing lower colloidal value of clay, also accounting for low moisture content.

Conclusions

We cannot at this time make any statement of the value of clay bond to the general user of molding sand, but we have endeavored to relate our experiences in trying to make use of it in the conservation of new sand.

The A. F. A. permeability apparatus was found to be most useful in the foundry while working with clay bonds. Although very strict attention was paid to the various characteristics of the heap as may be realized by the fact that some 17,000 sand determinations were made in our sand laboratory during the past year, havoc could be wrought if the sand was misused by the foundry through improper jolting or ramming.

The permeability of the mold, as determined by the Cornell permeability apparatus, made a valuable supplement to our study of the sand.

The molding sand heaps, throughout the entire plant, now employ clay bond. An appreciable saving has been made through its use. More important, however, we have maintained quality which, as we have stated early in our paper, was paramount.

Rejections, in spite of the use of clay bond and its early difficulties, have not exceeded previous periods when it was not employed.

As representative of the possibilities our experience indicates a saving of approximately 60 per cent in the case of both new sand and seacoal. To this must be added a material saving in handling charges, both within the foundry and to the waste pile.

It has required the undivided attention of the technical department and the foundry in order to make a success of clay bond additions. It has required the closest co-operation between the two departments and the recognition of the problem involved both from the technical and practical standpoint.

A few statements based upon our experiences might assist the new user of clay bond and they are gladly given in this spirit.

(1) Add clay bond in small percentages. (The tendency has been to employ clay bond to excess.)

(2) Distribute the clay bond uniformly and mix the heap involved intimately and uniformly as your particular case may demand.

(3) Add new sand to mixtures regularly or occasionally. This may keep your heaps away from the "ragged edge" and be economy in the long run.

(4) Make every effort to determine every characteristic of the molding sand heap, both in the plant and in the laboratory. It is slight changes in certain characteristics and recognition of these that tends toward success or failure.

(5) Take advantage of the A. F. A. tests, employ them to the fullest extent. Through their intelligent use your molding sand problems and the use of clay bond will be less difficult.

(6) Watch for accumulation of clay and seacoal.

(7) Pay strict attention to the amount and fineness of seacoal. It has a marked effect on permeability.

(8) If you are limited to a minimum number of tests, make frequent use of the permeability and the compression tests and know the permeability of your molds after having been jolted or rammed up.

The authors feel that our particular problem was at least not easy in that each casting is subjected to a very critical inspection when shipped to the customer as an unmachined casting. When it is further realized that the casting before being used by a consumer is machined to at least 95 per cent of its area and must be practically perfect, it is seen that our problem at least was a severe test for the merits of clay bond. When it is further realized that our rejections during the period of the use of clay has not increased and that our quality has not suffered, but in many instances has actually improved, it would seem that clay bond, intelligently employed with the A. F. A. sand tests, offers definite possibilities to the foundrymen.

Discussion

A. A. Grubb: Mr. Harrington said that by adding 4 to 8 per cent of new sand, it was sufficient to produce within the sand characteristics which eliminated to a very great extent the tendency towards scabbed castings. Did any laboratory test, any test you might put it to, indicate what those

characteristics are? In other words, have we any way of testing to predict what we are going to get?

R. F. HARRINGTON: I will say in that connection it was impossible for us to read the records of each day's sand heaps and obtain any indication that in a two weeks' period of time the sand was going to be in such a condition as to warrant new sand additions. Now, it is barely possible that we failed to carry on all the tests that we should carry on. There does seem to be occasions, from a very practical standpoint, sometimes, when you can't tie up the condition in the foundry with the sand test. But I think that is one case in a thousand rather than frequently. But it was impossible for us to predict, in other words, that that sand was going to run off.

J. F. HARPER: I would like to ask Mr. Harrington if he can tell the difference, or the relation between his laboratory test and his actual foundry test in the matter of permeability.

R. F. HARRINGTON: Yes. The laboratory test, for example, might give a permeability reading of 120 and the permeability in the foundry would drop down to 75. In other words, there was a difference there, possibly, of a cut of 40 to 50 per cent.

H. W. DIETERT: In reference to the scabbing of castings, we find that it is a combination of high strength and high moisture, that is, you have more new clay bond in your sand, an accumulation of new clay. That is, the clay should be non-active or non-plastic, you want the clay to get a little old. If you run your strength up too high and happen to get on the heavier side on moisture, you can't help but have a scab. I still think a person can use clay bond without the addition of new sand. As long as we realize that clay bond is a very concentrated material, if you keep your strength down to the proper limits and add old sand you will get along all right. We have time after time eliminated scabs by simply reducing the green strength of the molding sand, because it is the tendency of the molder to increase the green strength, because he doesn't have to ram so hard.

MR. WILSON: I would just like to ask what kind of clay Mr. Harrington used for getting strength.

R. F. HARRINGTON: We are using two Pennsylvania clays, both of which have been working satisfactorily.

W. G. REICHERT: I would like to ask Mr. Harrington whether or not he got any greater balling up effect on using the sand cutter and the paddle type of machine as compared to the muller type.

R. F. HARRINGTON: I would not say that we did. Of course, we obtained greater permeability. Now, then, if we obtained greater permeability, one might reason that the clay had been wrapped around the grain

structure and therefore allowed for the escape of the gases through the voids, but coincident with the change in method of mixing the amount of clay material was reduced, so that instead of endeavoring to wrap 3 per cent or 2 per cent of clay bond around the grain, we wrap now only ¾ of one per cent, and sometimes run down as low as a half of one per cent. The reason for that is that our old sand is not as old as many other foundries' old sand would be.

A. V. LEUN: I have found that if you had an excessive amount of clay in your sand and you mulled it, that clay would ball up and give you a greater permeability. One particular case I remember was, I had an Albany sand with a permeability of nine or ten. I mulled that sand and it was very fine, the clay was in excess, it balled up and at the end of about 30 minutes I had a permeability of about 22 mulled.

P. R. RAMP: This is a very interesting subject. A good many years ago when I started out to run a foundry my boss wanted me to put some clay in our old sand instead of buying new sand. Well, I thought that was a pretty good proposition, so I wrote home to my old dad about it. He wrote back to me and he said, "You can't make sand,—you'll have to buy it." So I am glad to have listened to this.

What Mr. Harrington said that struck me was this, that where you add new sand, you cut the sand two or three times, but when you use your clay addition, it is necessary to cut it eight or ten times. I am wondering what it costs between trying to cut it three times and the eight cuts. You know, this night gang you pay so much a heap, and if you have to cut that ten times, will it pay to put the clay in there instead of adding the new sand? That is the thing that I would like to ask.

R. F. HARRINGTON: We did feel it necessary to cut the sand over a greater number of times when we had the clay additions and the small percentage of new sand in contrast to the all new sand addition. Whether we can drop back now in the near future and get back somewhere near to the old figure or not I am not prepared to say. I regret, Mr. Ramp, that I can't tell you the exact difference in cost of cutting that heap over ten times as compared with three. As a matter of fact, the real costly operation, so far as our problem is concerned, is the screening, and the mere cutting of that heap an extra half dozen times is appreciable, to be sure, but I feel, offhand, it would add very little to the actual cost of tonnage of mixed sand.

A. C. PORTER: How do you add your clay in your muller? Do you add it as a clay wash or as a dry clay?

R. F. HARRINGTON: As a dry clay.

A. C. PORTER: I would like to tell my experience. Our sand out in Nebraska is pretty expensive. The freight we have to pay is excessive, and

we took clay from a brickyard and mixed it, 50 per cent water and 50 per cent clay, and put it in a muller type of mixer and took our old, burnt-out sand, which we used to carry to the refuse pile, and used that as additions in our regular heap every night. Of course, we were just experimenting, we didn't want to go into the expensive laboratory tests, so we just took the old clay bond or laboratory test, which we take every night. The result is that we have carried our plant for four months, making cylinder castings, flywheels and gasoline engine castings, without the addition of a bit of new sand, and I was wondering if it was the kind of clay we were using or the way we were putting it in that didn't give us much difficulty.

R. F. HARRINGTON: I regret that I can't relate any experiences as to the relative merits of adding clay in suspension or in the dry state. I am a firm believer, as you are, evidently, in the muller type of equipment. With us we have a very definite problem of permeability and we were a little bit concerned with our inability to obtain quite the permeability that we desired when we mixed the sand sufficiently intensively to get along without any new material. But I haven't a doubt but that in many shops, possibly in our own later on, we may be able to operate with a few per cent only of clay bond, and no new sand. Mind you, we operated for three and four months without any new material other than clay bond, but the grief seems to come. Sometimes it takes a year, or maybe six months, before your grief comes, and I regret that some of these conditions that arise we haven't been able to explain. I think they are explainable and I think that we are going to devise ways and means of explaining them. When they are explained, that day will be the day we can get along, possibly, with a reduced amount of new material. But where you have several hundreds of tons of sand involved and on a production basis, we prefer to go a little bit cautiously in cutting the new material down to a dangerous point.

C. H. ROSS: Has Mr. Harrington used river sharp sand at the end of his three months instead of ordinary band sand?

MR. HARRINGTON: Yes.

MR. ROSS: With good or bad results?

MR. HARRINGTON: No results whatsoever.

E. S. CARMAN: I think it might be well to have a little enlightenment upon this point. Since the degree of fineness of sand has much to do with the quality of castings, I would like to ask Mr. Harrington if he at the time he was experiencing troubles—and the tests apparently showed that—if he also had the sand analyses at hand and were they quite uniform or did they vary greatly?

R. F. HARRINGTON: They were very uniform. In fact, we couldn't detect by the tests that we were running any appreciable difference.

Some Experiments on the Refractoriness of Foundry Sands

By D. W. Trainer, Jr.,* Ithaca, N. Y.

Molding sands vary in their refractoriness, and since the grain of the material is probably usually silica, which of itself is quite refractory, it follows that the fusion point may be controlled in a large measure by the nature and amount of the bond.

It is a well known fact, however, that sands having the same amount of clay substance may have a different refractoriness, and these differences must be explained as due either to difference in texture, or difference in composition of the bond, assuming, of course, that both sands had been fired in the same atmosphere.

In the first series of experiments described in this paper, the two fixed factors were the clay and the sand, while the percentage of clay added to the sand was varied.

Raw Materials Used

The sand was a washed Pennsylvania glass sand which is nearly pure silica. The fineness test of this sand is given in Table 1.

A microscopic examination showed the grains to be all of white crystalline quartz, with the grains of angular to subangular outline.

The clay used was an impure glacial clay found near Ithaca. Previous to use it was finely ground and washed in order to eliminate sandy impurities. After washing it left but 1.25 per cent on a 200 mesh sieve. Cones of this washed clay were fired at several temperatures with the following results:

Cone 4 (1210 degrees Cent.) No sign of fusion or deformation.

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Cone 9 (1310 degrees Cent.) Fusion begun, cone slightly bent.

Cone 11 (1350 degrees Cent.) Cone bent over, tip touched base.

The chemical composition of the clay is given in Table 2.

If the undetermined material in the chemical analysis, viz. 1.22 per cent is considered as alkalies, then the total fluxes

Table 1.

FINENESS TEST PENNSYLVANIA GLASS SAND

Screen Mesh No.	Per Cent Material
6	0.00
12	0.00
20	.40
40	13.58
70	69.84
100	15.88
140	.90
200	.08
270	0.00
Pan	0.00
	100.68

Table 2.

CHEMICAL COMPOSITION OF CLAY USED IN TEST

Substance	Per Cent
SiO_2	66.08
Al_2O_3	17.50
Fe_2O_3	8.00
CaO	1.00
MgO	1.58
Ignition loss	4.62
	98.78

Table 3.

SAND CLAY MIXTURES USED IN TEST

Per Cent Clay	Per Cent Sand
10	90
20	80
25	75
30	70
35	65
40	60
50	50

present, including CaO, and MgO, amount to 3.80, or if we include the iron oxide it is 11.80 per cent.

Sand-Clay Mixtures

The sand and clay were then made up into a series of mixtures, as given in Table 3.

The ingredients of each mix were first ground dry, and then wet.

These mixtures were studied microscopically to determine the actual distribution of the clay after the mixture had been made. The following facts were noted in regard to the different mixtures:

10 per cent Clay—90 per cent Sand: There was no regular distribution of the clay in or among the sand grains. None of the grains showed complete coating with clay, and only a few showed patches of clay adhering to them. This seems to be accounted for by the small amount of clay present.

20 per cent Clay—80 per cent Sand: It would be quite natural to expect that a plastic clay similar to the one used in this mixture, would tend to bind the small particles of the quartz sand together first, and affect the larger ones later, when there was enough clay present to bring this about. This seems to be the sequence of events which have taken place in these samples, and the first stage is recorded in this mixture. In this mixture, the fine grains are adhering to one another and the majority of the larger grains are completely coated with clay.

25 per cent Clay—75 per cent Sand: The same thing has taken place in this mixture, except that there seems to be a thicker coat of clay, which can readily be decreased in thickness by rubbing the grains on paper.

30 per cent Clay—70 per cent Sand: This mixture shows a very thick coat of clay and fine sand on the larger grains, and some of the grains show compounding.

35 per cent Clay—65 per cent Sand: In this mixture the clay is in excess of the fine sand in the material found coating the grains, and many of the grains show compounding.

40 per cent Clay—60 per cent Sand: The clay coating of the grains seems to be very strong and the compounding of the grains seems to be much greater, at least there are more grains held together in one compound grain.

50 per cent Clay—50 per cent Sand: The grains that show coating are well coated, but relatively there are only a few grains

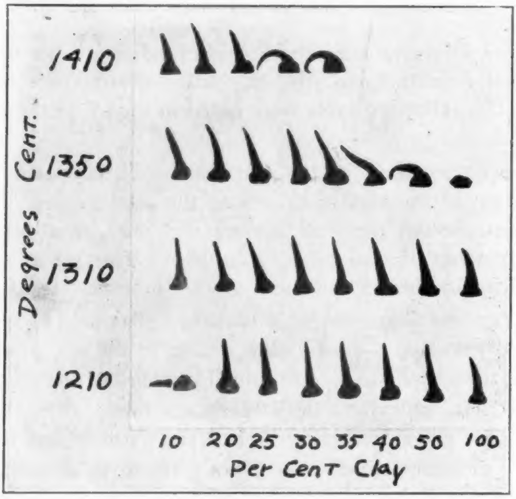

FIG. 1—PHOTOGRAPH OF FIRED SAND-CLAY MIXTURE CONES

in comparison with the number of fine clay particles around them.

Firing Tests

The mixtures described above were made into cones and these carefully fired in a muffle, the temperature being checked by a thermo-couple, and the range of temperature being from 1000 to 1510 degrees Cent. The atmosphere was probably oxidizing.

The results of the firing tests on the cones of these artificial mixtures is shown in Fig. 1. At 1210 degrees Cent. none of the

cones showed any signs of fusion or bending, and were of a pinkish red color. At 1310 degrees Cent. no fusion or bending was noted, but all the sand-clay mixture cones and the clay burned to a dark chocolate color. At 1350 degrees Cent., only 40 degrees Cent. higher than the preceding test temperature, the clay and the 50 per cent clay mixture failed completely. The 40 per cent mixture showed almost complete failure, while the 35 per cent mixture showed only slight bending. The rest of the cones showed practically no bending, but all show that the bond has fused appreciably. Only the cones which showed no bending were fired at the next temperature, 1410 degrees Cent. At this temperature, the mixtures with 35 per cent and 30 per cent of clay failed completely by fusion.

Some very definite conclusions can be drawn from this experiment. None of the sand failed until the bonding clay failed. At the temperature of complete fusion of the clay, sand-clay mixtures above 35 per cent clay showed little fusion to complete fusion at 50 per cent clay. With increases in temperature, the mixtures of lower clay contents show fusion. By starting with these results, a general law may be derived. This may be stated in the following manner: Sand-clay mixtures (molding sands) show failure in cones by complete bending at the temperature of fusion of the clay, if the mixture has 50 per cent of clay and the failing temperature increases as clay content decreases, as shown in the graph of Fig. 2.

The curve shown in Fig. 2 shows the relation just stated in a graphic way for a specific case, where the clay and the sand-clay mixture containing 50 per cent of the clay fused at 1350 degrees Cent. It will be noticed that the curve becomes a straight line for mixtures of higher clay contents, which indicates that they will all be controlled by the fusion point of the clay. The points on the curve were actually located by firing tests until the limit of the furnace was reached, 1510 Cent. Above this, the fusion point of quartz is placed as a mixture with no clay, and the curve is continued to this point. The dotted portions of the curve indicate what probably happens in these regions.

It has been suggested that this work can be carried further with mixtures made of clays of different compositions, and thus different fusion points. This, of course, would add to our knowledge of the subject, but it seems very evident from the work done with the molding sands, which will be discussed later, that curves similar in characteristics to Fig. 2 would be obtained, with possibly slight variations. Of course, clays with lower fusing points would fall below the curve in Fig. 2 and probably be somewhat flatter, while the clays of higher fusion points would fall above and probably be somewhat steeper.

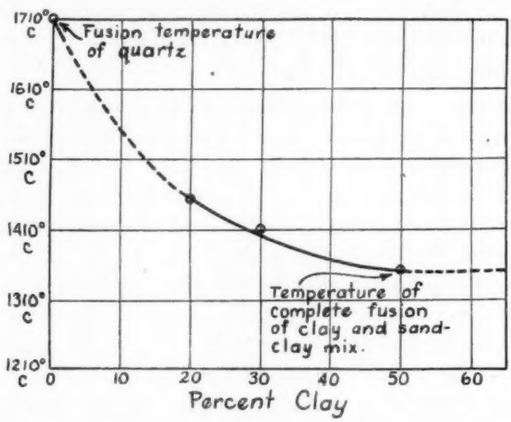

FIG. 2—CURVE TO SHOW THE RELATION BETWEEN THE FUSION TEMPERATURE OF SAND-CLAY MIXTURE AND THE PER CENT OF CLAY IN THE MIXTURE

In concluding the work done on the cones made of the different sand-clay mixtures, it seems to the writer that this method is of qualitative rather than quantitative value.

Bars

In the next series of test bars of the different sand-clay mixtures, 3 x 1½ x ¼ inches, were made up as described before and allowed to air dry before firing. These bars were exceptionally strong for artificial mixtures.

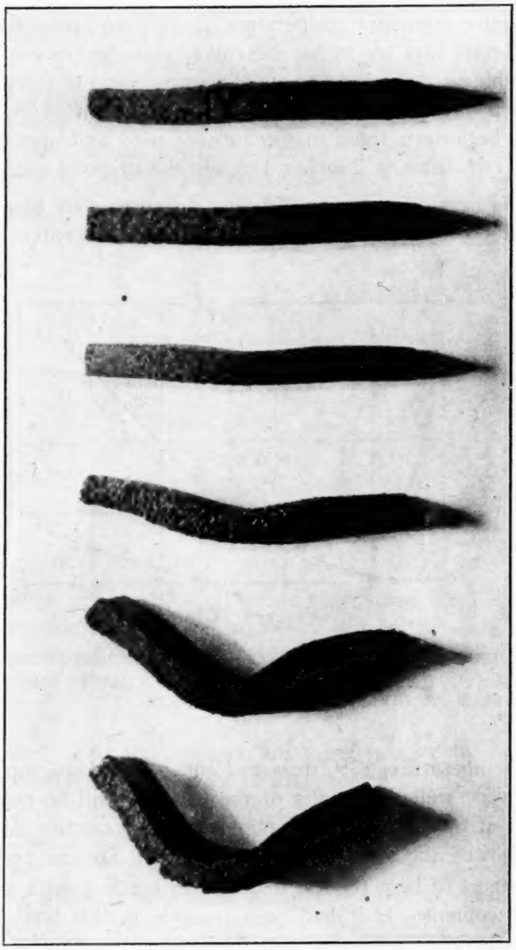

FIG. 3—PHOTOGRAPH OF SAND-CLAY MIXTURE BARS FIRED AT 1350 DEGREES CENT. WHICH SHOW THE RELATIVE AMOUNT OF BENDING IN MIXTURE OF DIFFERENT CLAY CONTENT

The choice of the size of the bar, especially the two smaller dimensions, was more or less arbitrary. Square bars were tried but require a greater temperature to give an appreciable bending. Round bars are rather difficult to make because it is almost impossible to ram all parts equally in a tube and then push the specimen out without fracturing it. The length of the bar was chosen because it fitted in the furnace used and also because it gave a fair distance, 2 inches, between the supports used in firing.

The bars of the seven different mixtures were placed in the furnace on fire clay knife edges with two inch centers and fired

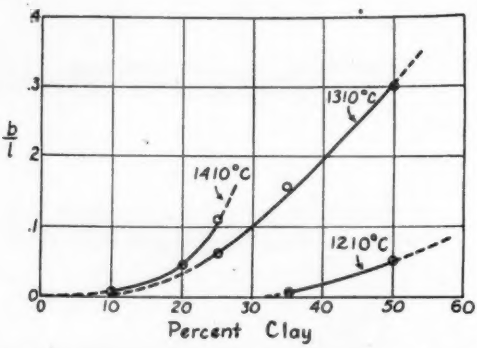

FIG. 4—CURVES TO SHOW THE RELATION OF BENDING $\frac{b}{L}$ IN SAND-CLAY MIXTURE BARS, TO THE PER CENT OF CLAY IN THE MIXTURES, FIRED AT DIFFERENT TEMPERATURES

at one temperature, 1350 degrees Cent. The photograph, Fig. 3, shows very well the results of the test. It will be noticed that the bar at the bottom of the photograph, containing 50 per cent clay, showed the greatest bending. It will also be noticed that there seems to be a regular decrease in bending with a decrease in clay content. If it had been possible in this work to carry the testing over a greater range of temperature, it would have been possible to show that the amount of bending is not exactly a straight line function, but a smooth curve. This is very evident from the data shown in Fig. 4.

The data used in drawing the curve shown in Fig. 4 was obtained in the following manner. Two sets of bars were fired at 1310 degrees Cent., and the amount of bending calculated. The calculation was made as follows: the edge of each bar was traced on a paper and a straight horizontal line drawn between the two support points. The length of this line is two inches and has been designated as L. The length of the vertical line or maximum amount of bending has been designated as b. The value of $\frac{b}{L}$ is plotted against the per cent of clay in the bar for each temperature of firing.

Table 4.

SAGGING OF TEST BARS

1210 degrees Cent.		*1310 degrees Cent.*		*1410 degrees Cent.*	
Per Cent Clay	$\frac{b}{L}$ in Inches	Per Cent Clay	$\frac{b}{L}$ in Inches	Per Cent Clay	$\frac{b}{L}$ in Inches
50	.05	50	.3	25	.11
35	.005	40	.2	20	.045
		35	.158	10	.01
		25	.063		

The results of the tests are given in Table 4.

It will be noticed in Fig. 4 that the curves for the higher temperature are steeper than those of the lower temperature. This is what would be expected because at the lower temperature only softening of the clay bond would show by bending of the bars.

This method of testing the relative softening point of sand-clay mixtures gives quantitative results that are easily compared. Besides testing the softening point of the different mixtures by noting the amount of bending, complete fusion may be noted when the bar loses its original shape and sags to the bottom of the furnace muffle. It should be added, however, that a bar test is not found applicable to sands lacking bond.

Comparison of Cone and Bar Tests

It has already been pointed out, that the amount of bending shown by a cone and the temperature of complete fusion are both

factors to which it is very difficult to assign quantitative figures. Another difficulty encountered in the testing of cones is making all the cones the same, both as to height and size of base. This factor is an important one, because it has been noticed that long slender cones will show complete bending at a lower temperature than a short stout cone of the same material.

On the other hand, if a standard mold box is used to make the bars, and these are used as test specimens, the difficulty of varying sizes and shapes of the pieces may be overlooked. Probably the greatest advantage that the bar bending test has over the cone method of testing is that the results of the test may be expressed in a quantitative way which will have a definite meaning to all.

Procedure of Test

Bars of the several molding sands or sand-clay mixtures which are to be tested are made up in the mold box from sand tempered to a good feel and allowed to air dry for at least 24 hours. The bars are then placed in the furnace and heated to the desired temperature. The bars are removed from the furnace and the ratio $\frac{b}{L}$ calculated for each bar; by comparison of these figures the amount of softening of each sand may be noted.

It is suggested that some standard temperature be set for burning sands that are used for casting the different metals, such as 1000 degrees Cent. for brass and aluminum, 1350 degrees Cent. for iron, and 1600 degrees Cent. for steel.

No standard figure for the ratio $\frac{b}{L}$ can be given here for any of the standard sands, because they were not available when this work was done. It would be a relatively easy problem, however, to set a figure with certain limits which could be used by all as a guide in purchasing new sands or evaluating new deposits.

Tests of Molding Sands or Natural Sand-Clay Mixtures

Selection of Samples

From the work already completed, some excellent ideas were obtained in regard to the action of sand-clay mixtures on heating. It was thought best to select a series of samples for these tests which contained nearly the same clay content but came from different locations and had different modes of origin. Thirty-two samples with which the author was familiar were selected, and these are listed in Table 5 with their clay content as determined by the American Foundrymen's Association fineness test. Their formation is also given.

Table 5.

SAND SAMPLES USED IN TEST

Sample No.	Per Cent Clay	Formation
1524	9.06	Magothy Formation—Maryland Coastal Plain
833	9.46	Glacial Lake Jean Nicolet, Berlin, Wis.
1525	9.70	Aquia Formation—Maryland Coastal Plain
878	9.80	Terminal Moraine—Merrimac, Wis.
871	9.90	Glacial Lake Baraboo, Kirkwood, Wis.
801	10.08	Glacial Lake Chicago, South Milwaukee, Wis.
1517	14.10	Aquia Formation—Maryland Coastal Plain
1508	14.30	Matawan Formation—Maryland Coastal Plain
810	14.46	Abandoned terrace of Rock Rivers, Beloit, Wis.
872	15.18	Glacial Lake Baraboo, Kirkwood, Wis.
1527	15.56	Sunderland Formation—Maryland Coastal Plain
1509	15.76	Aquia Formation—Maryland Coastal Plain
815	17.38	Outwash Terrace, Janesville, Wis.
875	19.04	Glacial Lake Baraboo, Ableman, Wis.
1513	19.10	Lafayette Formation—Maryland Coastal Plain
1534	19.80	Sunderland Formation—Maryland Coastal Plain
812	19.84	Rockton, Ill.
838	20.50	Glacial Lake Jean Nicolet, Berlin, Wis.
1506	20.08	Aquia Formation—Maryland Coastal Plain
828	21.56	Stream Terrace, Scandinavia, Wis.
848	24.24	Glacial Lake Jean Nicolet, Berlin, Wis.
816	24.34	Outwash Terrace, Dousman, Wis.
882	24.76	Rockton, Ill.
1507	24.76	Matawan Formation—Maryland Coastal Plain
809	24.94	Abandoned Rock River Terrace, Beloit, Wis.
1520	25.82	Sunderland Formation—Maryland Coastal Plain
808	27.42	Outwash Terrace, Bassett, Wis.
814	29.52	Outwash Terrace, Janesville, Wis.
806	30.82	Outwash Terrace, Wheatland, Wis.
831	36.88	Glacial Lake Jean Nicolet, Berlin, Wis.
807	41.40	Terminal Moraine, Bassett, Wis.
836	47.42	Glacial Lake Jean Nicolet, Berlin, Wis.

It will be noticed from Table 5 that samples were selected with the following clay content: 10, 15, 20, 25 and 30 per cent, and a few with greater per cents more. An allowance of 1 per cent was made for most of the samples selected, and those in any one group are not from the same locality, but may have had a similar origin.

Sand Grains

Some have thought that the size of the grain may have an influence on the refractoriness of the sand. This in general has been found not to be true. The coarseness figure as determined by the author will be given for each sand and it will be shown later that in any group of a given clay content the coarseness has played little or no part in the resistance of the sand to heat.

Table 6.

SAND SAMPLES AND COARSENESS NUMBERS

Sample No.	Coarseness Figure	Sample No.	Coarseness Figure	Sample No.	Coarseness Figure	Sample No.	Coarseness Figure
1524	.875	810	.854	812	.841	809	.572
833	.506	872	.559	838	.551	1520	.495
1525	.538	1527	.745	1506	.973	——	——
878	.555	1509	1.116	——	——	808	1.192
871	.622	——	——	828	.796	814	.591
801	.298	815	.903	848	.577	806	1.154
——	——	875	.546	816	1.733	831	....
1517	.619	1513	.576	882	.353	——	——
1508	.707	1534	.952	1507	.683	807	.454
						836	.411

Table 6 giving coarseness figures shows that there is enough difference in the coarseness of each of the sands in the different groups so that any effects due to this, if there are such, will show in the firing tests of the sands.

Two other factors that may influence the refractoriness of naturally bonded sands, and which may be obtained from a microscopic study of the separates of the screen analysis, are: (1) the mineralogy of the grains, and (2) the amount of natural stain on the grains.

In studying the mineralogy of the grains little attention was paid to any of the minerals except quartz, all others being considered as impurities. In most cases mineral counts were made

in order to determine the actual percentage of impurities in each separate. From these figures estimates have been made of the purity of the sand grains on a quartz basis. In certain of the sands collected, it was found that the grains were entirely or partially coated with iron stains. Estimates have also been made of this, because it may be an important factor in starting the fusion of the quartz, since in such cases, a flux is in very intimate contact with the quartz grains.

In Table 7 the percentage purity of the grains on a quartz basis, and the percentage of stained grains are given for most of the sands tested. The sands are arranged in order of clay content as they were tested.

Table 7.

Laboratory No.	Per Cent Purity	Per Cent Staining	Remarks
1524	93	26	
833	94	36	
1525	94	55	
878	98	2	
871	97	32	
801	87	57	Lime cement in coarse grains.
1517	55	25	
810	94	36	
872	97	56	
1527	99	47	
815	98	19	
875	91	55	
1534	96	14	
812	89	49	Lime cement in coarse grains.
828	98	20	
848	96	32	
816	82	2	
882	86	42	Lime cement in coarse grains, and some small ones.
1520	83	81	
808	80	35	
814	97	16	
806	67	8	
831	96	23	
836	92	40	
807	90	35	

The data given in Table 7 has been studied to ascertain if there is any definite relation between the two factors given in the table and the fusion temperatures of the sands. No definite relation was noticed, but several facts were disclosed which lead the author to think that these factors have some bearing on their refractoriness. Sands which contain some lime cement, in

general, show lower fusion temperatures. Also sands that contain a large percentage of impurities, as well as those which are badly stained, seem to have a lower fusion temperature, even though they contain the same general type of clay. Examples of this are seen in sands numbers 1525 and 1517. The bonding clay extracted from these sands showed similar refractory properties, but the tests of the natural sand-clay mixtures (molding sands) showed varying properties of refractoriness. Sand, number 1525, was the most refractory, showing complete fusion at 1510 degrees Cent. Its grains were 94 per cent pure and showed 55 per cent staining, while sand, number 1517, which was almost completely fused at 1410 degrees Cent., was 55 per cent pure and showed about 25 per cent of its grains stained. It would appear from this that the purity of the sand grains had some effect on the refractoriness of the mixture.

Extracted Clays

After noting the action on firing of several of the molding sands with the same clay content, as determined by the American Foundrymen's Association fineness test, it was decided to test the refractoriness of the clays in these sands after they had been separated from the sand grains.

The separation was accomplished in the following manner: four 50 gram samples of the molding sand were placed in quart jars, which were nearly filled with tap water, corked, and then agitated for thirty minutes. No flocculating agent was used because it was desired to have the clay as pure as possible for the testing. After the agitation the samples were allowed to stand ten minutes, and then the clayey water was siphoned off and collected. The jars were filled again, the material being stirred by the jet of water used in filling, and then allowed to stand for ten minutes, and then at five minute intervals the same procedure was repeated until it was impossible to suspend any of the clay in the water. The clayey water was allowed to stand in the collecting tank until it became clear. The water was then siphoned off. The clay was collected from the bottom of the tank and dried before testing.

The clays extracted from the eleven molding sands selected for this test were made up into cones and fired at successive temperatures until they all reached their temperature of complete fusion. It was found that many of the clays fused completely

Table 8.

Laboratory Number	Grade	Fusion Temperature Degrees Cent.
833 1508	A	1410
1520 F.H.W. 815 810 808	B	1350
1517 872 1525	C	1310
878 875	D	1250

Table 9.

ANALYSES OF CLAYS* FROM MOLDING SANDS

	Grade A No. 833 Per Cent	Grade B No. 1520 Per Cent	Grade C No. 1517 Per Cent	Grade D No. 878 Per Cent
SiO_2	69.10	54.80	55.33	57.73
Al_2O_3	15.35	22.60	21.50	12.67
Fe_2O_3	6.85	8.57	8.00	6.85
CaO	1.60	.75	.90	.75
MgO	.20	.30	1.72	1.00
Alkalies as K_2O	....	....	....	6.33
Loss on ignition	5.80	10.14	8.20	13.70
Total	98.90	97.17	95.65	99.06
Total Flux	9.83	12.45	14.97	15.88
$SiO_2+Al_2O_3$	84.45	77.40	76.83	70.40

*Analyses by G. W. Cavanaugh.

at approximately the same temperature and thus could be grouped according to their refractoriness.

In Table 8 the laboratory number of the sand from which the clay was extracted, the grade of the clay according to its refractoriness, and the temperature of complete fusion of the clays of that grade are given.

From each one of the grades given in Table 8 one clay was selected for chemical analysis, in order to see what effect its composition had on the fusion temperature of the clay. These analyses are given in Table 9.

Some very interesting relations may be drawn from the chemical analyses of Table 9 in regard to the refractoriness of the clays. It is noted that the total fluxes, determined from the sum of Fe_2O_3, CaO, MgO, alkalies, and undetermined material, increases as the clays decrease in refractoriness, and that the sum of SiO_2 and Al_2O_3 determinations increases with the re-

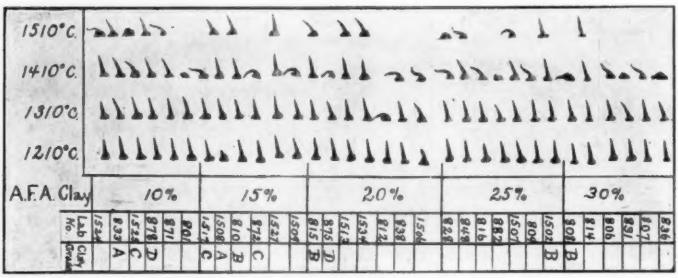

FIG. 5—MOLDING SAND CONES AFTER FIRING

fractory properties of the clays. There does not seem to be any relation between the amount of iron and refractoriness.

Molding Sands

In the preceding discussion it has been noted that the bonding clays of molding sands have different refractory properties. It is now possible to show in a qualitative way the relation between these facts and the fusion temperatures of molding sands.

In Fig. 5, thirty-two different molding sands are shown in cones which have been fired at different temperatures. These are arranged, from left to right, in order of clay content as determined by the American Foundrymen's Association fineness test, and the different rows represent the various firing temperatures, the first or bottom, 1210 degrees Cent., second, 1310 degrees Cent., third,

1410 degrees Cent., and the fourth or top, 1510 degrees Cent. Besides the laboratory number of the sand, the refractoriness grade letter of the bonding clay is given below.

If now, the failure of the sand cones is considered with respect to the clay content of the different groups, the following is noted. The cones fired at 1210 degrees Cent. may be neglected because there were no failures at this temperature and those fired at 1310 degrees Cent. may also be neglected, because the only failure at this temperature was number 812, which is a high lime sand. At 1410 degrees Cent., 16 per cent of the sands in the 10 per cent clay group failed, 50 per cent in the 15 per cent clay group, 42.8 per cent in the 20 per cent clay group, 57.2 per cent in the 25 per cent clay group, and 75 per cent in the 30 per cent clay group. Approximately the same relation has been worked out for the sands fired at 1510 degrees Cent., except, of course, that there were a greater percentage of failures at this temperature. Consequently it may be said, in general, that molding sands fail according to their clay content.

Now, let us consider a particular group, taking for example, the sands containing 15 per cent of clay. It will be noticed that 50 per cent of the sands in this group failed at 1410 degrees Cent. and 50 per cent at 1510 degrees Cent. Aside from this, there does not seem to be any order in the failure. For example, samples, numbers 1508 and 810 stood at 1510 degrees Cent., while numbers 1517 and 872 failed on either side of the ones mentioned. The only and best explanation that can be made for this, is that the clays bonding the sand grains have different refractory properties. If now, Fig. 5 is referred to again, it will be seen that two sands, numbers 1508 and 810, which stood at 1500 degrees Cent., have bonding clays that have been classed as A and B grades according to their refractoriness, while the two sands, numbers 1517 and 872, which failed at 1410 degrees Cent. have clays that are classed in the C grade. Other similar examples may be noted on Fig. 5. These facts seem to show that sands of the same clay content may fail at different temperatures according to the refractoriness of their bonding clays.

Conclusions

There are certain facts which it seems to the author should be emphasized as a result of the information obtained from the foregoing experiments.

In making comparative fusion tests the condition of the furnace atmosphere should be kept as uniform as possible.

Two distinct heat properties of the sand should be recognized, viz: (1) incipient fusion, and (2) complete fusion.

The former, in the case of bonded sands, can perhaps be better tested by the use of bars than by cones, and gives more quantitative results.

In general the fusion point of a sand appears to be determined by the fusing point of the bond.

While in general also molding sands appear to fuse in the order of their clay content, there are not a few exceptions, which are evidently due to variations in the refractoriness of the different bonds. The size of the grains, and the presence of impure films on them, exerts some effect, but it is of secondary importance.

Discussion

J. Grennan: The average foundryman, I think, wants a complete test that he can use without any modification or experimenting with it. The question of using the experiments in the foundry is what I am thinking of. The average foundryman wants a test that has been made almost foolproof. Now, if you will remember, in the start on the sand test the steel foundries made the most progress at the start, and yet they changed some of their recommendations after they worked them over in their shop another year, and this test may be so new that it may be possible that the foundrymen at the present time may be interested in it more as a laboratory proposition than as a control in a shop. I would like to ask if the author of the paper would recommend that any foundryman try to follow his methods at the present time, as far as sand control is concerned.

D. W. Trainer: The tests were not designed, of course, for shop control work. However, I feel that any one who is testing new sand, and has any sort of a laboratory at all, could use this bar sagging test as an indication of the refractoriness of a new sand. Of course, it is not a control feature and I can't conceive of any way that we need it for a control test. If you are in a steel foundry and you want to know the refractoriness of your mix, you have to get at the parts that you put into the thing. Of

course, if you are using a quartz sand, you know that that is going to stand up, but you want to know something about the clay and how it is going to work when it is mixed. The testing of mixtures would have to be done in the laboratory and not in the shop, I believe.

CHAIRMAN R. A. BULL: I would like to correct Mr. Trainer's statement about the question as it applies to practical operations in a steel foundry. Many steel foundries use for facings a considerable proportion of heap sand, and through a reasonable period of time, due to the ordinary operations in the foundry, that heap sand may contain many varieties of materials, and the composition of that heap sand varies tremendously from week to week or from month to month. It will contain many things that are unprofitable to use, and many of which affect the fusability of the mixture.

MAJOR L. L. ANTHES: I was very much interested in the test shown there by the last speaker. Of course, there is a point that appeals to a great many foundrymen. Say a foundryman has a line of light castings and has to pour that with very hot iron; he is very often troubled with cuttings in and around the gates and the foundryman is worried as to how to overcome this trouble, and sometimes he gets the explanation that his sand has a low fusing point.

Now, as demonstrated by the reader of the last paper, the clay content and the character of the clay seem to play an important part with regard to the fusing of those sands, and that would indicate the fusing points in sands are more or less determined by the quality and quantity of clay, and sometimes it is advocated that a certain amount of fireclay be added to your sand, not only as a bonding factor, but as a factor to raise the fusing point. I would like to know if the reader of the last paper has been following out his test in connection with practical foundry work.

D. W. TRAINER: I am in an unfortunate situation, I am not a foundryman and I can only speak from what I have done in the laboratory. Of course, some say that scabbing and cutting, as you mention, are due to sand that has been not refractory enough, but I am at a loss to say exactly what these troubles are due to. I can say that I have tried fireclays in mixtures and you can't get the mixtures to fail if you put fireclay in them. That would bear out one of your points.

C. A. HANSEN: We have had more or less trouble with the sintering, or even fairly complete fusion of sand where the sand is enclosed in pockets, or partly enclosed in re-entrant angles along the flanges of heavy steel castings. Our operating conditions are rather severe in that we are required to pour these heavy castings and also light section castings from the same ladles, so that the heavy castings are poured somewhat hotter than they might otherwise be, but still our pouring temperatures seldom exceed 1575 degrees Cent. with steel of about 0.30 per cent carbon and its melting point

of about 1500 degrees Cent. In particular does this difficulty lead to excessive cleaning costs where it is absolutely essential that every particle of sand be removed, as is the case with steam passages in turbine shells and the like. I have therefore been interested in trying to find sand-clay mixtures which would be sufficiently refractory to avoid any possibility of sintering under our steel foundry operating conditions, and I am now pretty thoroughly convinced that I have been seeking a degree of refractoriness which is inherently impossible in this class of materials.

I have assumed that the only commercially practicable base for a steel foundry molding sand is silica, and that the most practicable bonding material is a highly refractory and reasonably plastic clay. The best of our clays are composed almost entirely of silica and alumina, so it follows that our sand-clay mixtures are composed almost entirely of silica and

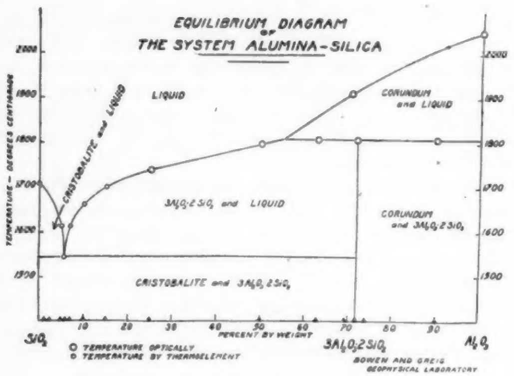

FIG. 1

alumina. Bowen and Grieg, of our National Geophysical Laboratory, have studied the temperature characteristics of the whole series of silica-alumina mixtures, and they developed a diagram reproduced in Fig. 1. This diagram indicates equilibrium conditions, at atmospheric pressure, without regard to the time required to attain equilibrium. This time period may be a matter of seconds, or a matter of months, depending upon the fineness of the constituents of the original mixture, the intimacy of contact between the constituents, and the temperature range involved.

The equilibrium condition, however, is the only stable condition. It is to be noted that the least refractory mixture of alumina and silica contains about 5 per cent alumina and about 95 per cent silica,—about the equivalent of 15 to 20 per cent good siliceous fire clay and 85 to 80 per cent pure silica sand; this is the eutectic composition with a melting point of about 1540 degrees Cent.—rather well under average steel pouring

temperature. But any mixture of silica and alumina, containing from a small fraction of 1 per cent alumina to about 72 per cent alumina, will contain some eutectic liquid under equilibrium conditions at 1540 degrees Cent., and this eutectic liquid can serve to sinter the mass. The only compositions of silica and alumina that can remain wholly solid at temperatures higher than 1540 degrees Cent. are those containing more than 72 per cent alumina, and these will remain solid up to slightly above 1800 degrees. Cent. These very high alumina compositions are not commercially practicable for ordinary foundry purposes, but it is quite possible that they might be used to meet special conditions.

Bradshaw and Emery (Foundry Trade Journal, Vol. 29, p. 447, 1924) experimented with the refractoriness of silica sand-clay mixtures, containing from 0 to 100 per cent clay. I am familiar with this work only through a rather unsatisfactory abstract (Stahl u. Eisen, Vol. 44, p. 1528, 1924), so that I am not certain of the procedures followed, but it seems that they heated cores under atmospheric pressure and under pressures of 25 pounds per square inch, using Seger cones to measure melting temperatures. I interpret the results they obtained in Table 1.

Table 1

Per Cent Silica Sand	Per Cent Clay (Schammotte)	Melting Point °C Atmospheric Pressure	Pressure 25 lb./sq. in.
100	0	1750	1620
90	10	1730	1560
80	20	1650	1510
70	30	1630	1480
60	40	1610	1470
50	50	1630	1490
40	60	1690	1510
30	70	1730	1520
20	80	1750	1540
10	90	1770	1540
0	100	1790	1540

I am not clear as to whether Bradshaw and Emery operated in a compressed atmosphere at 25 pounds absolute pressure, or under 25 pounds gauge pressure (above atmospheric pressure), or with a superimposed mechanical load. There is also serious question as to their definition of melting, and there is always serious question as to temperature scale defined by Seger cones.

Bradshaw and Emery place the melting point of silica at atmospheric pressure some 40 degrees above the commonly accepted melting point, and their lowest melting point mixture still melted at 1610 degrees or about 70 degrees above the Bowen and Grieg eutectic. These differences may be a measure of temperature scale inaccuracies. But the "melting points" for the entire series were dropped 130 to 150 degrees Cent. by a moderate increase in pressure, so I infer that a moderate increase in pressure may lower the Bowen and Grieg eutectic melting temperature to something like 1540—(130 to 150) or, say, 1400 degrees Cent. This is getting into a

temperature range in which steel has considerable tenacity, and the shrinking casting may readily exert considerable pressure upon enclosed, or partly enclosed, sand.

Silica and silica-alumina compositions do not melt sharply at a definite temperature in the sense that ice melts at 0 degrees Cent. to form a thinly fluid water; they are at best viscous solutions. I heated a pure quartz glass plate, 2 inches in diameter by about 1/8 inch thick, supported at its center upon a 1/2 inch diameter quartz rod, in an electric tube furnace. Ten minutes of exposure at 1600 degrees Cent. caused the quartz plate to assume an umbrella shape under its own weight; quartz, then, is fluid at 110 degrees Cent. below the commonly accepted melting point, although it is an extremely viscous fluid. I have seen pure silica sand cores pretty completely fused when wholly enclosed in heavy steel castings, and I believe that the work of Bowen and Grieg and the work of Bradshaw and Emery strike to the roots of the refractoriness problem of the steel foundry or, for that matter, of foundries in general.

Foundry sand mixtures are by no means homogeneous products capable of attaining equilibrium in short time periods, but the clays contained in them are, in general, fairly homogeneous mixtures which should be capable of attaining equilibrium in fairly short time periods. If the clay melts, in whole or in part, the fluid serves to cement together the sand grains in the mixture with the result that the sand becomes a sintered mass as soon as the fluid congeals. Nor is this the only effect; the fluid eutectic serves as a splendid solvent for silica, and as an excellent diaphragm through which alumina can diffuse from the clay into the sand grain.

It is theoretically possible for alumina in the solid clay to diffuse into the solid sand grain, but experimental work which I have done indicates that the diffusion rate is so slow that we can neglect it. As soon, however, as the temperature is increased to the point where any liquid is present the diffusion rate is rapid; the resulting absorption of alumina by the sand grain is naturally such that the alumina concentration at the surface of the sand grain is high relative to the alumina concentration at the center of the sand grain; the sand grain tends to acquire a fusible surface shell and, no matter how completely adhering clay may be removed from the sand grains by reclamation processes, it is my present opinion that reclaimed steel foundry sand can never be quite as refractory as the original clean silica sand.

I have started a rather exhaustive series of experiments to follow up some of the matters suggested above, and I have had some 37 different clays submitted to me for test as possible bonding clays for molding sands. These clays have been tested for refractoriness by making them into cones which were heated in an oxidizing atmosphere in gas fired furnaces and in a pure hydrogen atmosphère in electric furnaces. Cores were also made from each of these clays, using 10 parts by weight of clay to 100 parts by weight of washed Ottawa silica sand. These cores, 3/4 inches diameter by

¾ inches high, were molded in the usual way, baked at 180 degrees Cent., heated to about 650 degrees Cent. to dehydrate them, and then immediately heated to temperatures in the 1450 to 1600 degrees Cent. range in both oxidizing and reducing atmospheres. The differences in refractoriness between straight clays are greater than the differences in refractoriness between sand-clay cores. There is no appreciable difference in refractoriness, for straight clays or for sand-clay cores as between oxidizing and reducing atmospheres except with clays that contain appreciable amounts of iron oxide; clays containing appreciable amounts of iron oxide are less refractory in an oxidizing atmosphere than in a reducing atmosphere. Highly aluminous clays are more refractory than highly siliceous clays, but the difference practically disappears when both clay types are blended with silica sand in common foundry proportions.

I am convinced that the testing of sand-clay cores for refractoriness is more important than the testing of straight clays. With but two or three exceptions, all of the clays tested as sand-clay cores have been highly refractory clays. Cores made from any of the refractory clays, heated for 10 minutes at 1400 degrees Cent. in hydrogen, did not sinter perceptibly; in fact, most of them decrepitated to a loose powder when cooled, and few of them could be handled without breaking them. Very few of the cores made with refractory clays sintered appreciably at 1500 degrees Cent., although most of the cores were strong enough so that they could readily be handled. Every single core tested to date has sintered completely, glazed, shrunk considerably, and distorted badly when heated for 10 minutes at 1550 degrees Cent., and there has been every indication that complete fusion would take place were this temperature maintained for materially longer periods than 10 minutes.

It is certain that for 22 highly refractory clays tested as sand-clay cores, the temperature range in which they sinter at atmospheric pressure varies only between 1500 and 1550 degrees Cent., so that purely laboratory methods of determining refractoriness require unusually accurate temperature control and unusually accurate temperature measurements. The steel foundry operates in a temperature range which practically coincides with this critical temperature range of the best of clay-sand compositions, so that very slight differences in refractoriness, as measured on a temperature scale, can readily account for the differences noted in the foundry between mixtures that give considerable trouble and mixtures that give but little trouble.

Pressure, in so far as it increases the mobility of viscous fluids, will unquestionably lower the critical temperature range at which sand-clay mixtures sinter. This is, without question, the reason that sand mixtures will sinter badly in casting pockets, and when partly enclosed by the casting along flanges, etc. Sand-clay mixtures that are fool proof in respect to refractoriness in the steel foundry appear to me to be inherently impossible. The critical temperature range of this class of materials is,

however, so far above the working temperature range of the present day iron and brass foundries that refractoriness should not be in any way a serious problem. The Germans are now advocating cast iron temperatures in the 1500 to 1600 degrees Cent. range and adduce evidence to warrant the use of such high temperatures. If, or when, the iron foundry operates in this steel foundry temperature range, the refractoriness problem will become acute; perhaps the majority of naturally bonded sands now used in the iron foundries of this country will fail lamentably when metal temperatures are materially increased above present standards.

MR. ROSS: I would like to ask Mr. Hansen if the future of sand control lies in synthetic sands as far as his experience indicates.

C. A. HANSEN: I do not like the term synthetic sand, and I think the term is frequently misused to include this matter of rebonding sands that has cropped out so severely in the past few years. In a sense our cores sands, our dry sand and green sand mixtures are all synthetic sands; a great many of our so-called naturally bonded sands are synthetic mixtures. Personally, I have used the term to cover primarily mixtures of clean "sharp" sand with clay, to which may be added various organic binders as circumstances may require.

I have no preference supported by adequate observation for synthetic mixtures of clean sand and clay as against naturally bonded molding sands. It so happens that the foundries in which I am most interested are located in, or close to the Albany sand district, so that naturally bonded sands which are suitable for most of our iron and brass foundry work are cheaply available to us. I have seen little or no reason to believe that we can make better castings, or cheaper castings, by substituting synthetic sands for Albany sands where we are now using Albany sands. By the same token, I am convinced that we cannot make better castings, nor castings as cheaply by rebonding used Albany sands in order to reduce sand consumption. If we go to higher pouring temperatures in our iron foundry, and I am reasonably certain that we shall do so, then we shall be forced to break away from Albany sands for a considerable fraction of our work. We may be forced to use synthetic sands, and we will hope that the higher cost of these sands will be somewhat more than compensated for in other directions.

I am certain that we can make excellent castings of all kinds in synthetic sands; I am equally certain that if we are to better our sand conditions by changing to synthetic sands we will have to control our synthetic sands more closely than we now control our naturally bonded sands and to exercise this better control will require considerable remodeling of our foundries to permit the necessary transportation of materials.

I believe that proper control of sand requires a central sand conditioning plant for each foundry unit, and this control must extend to the point where the sand finally is rammed into the mold; the control must be

taken out of the hands of the individual molder unless the individual molder is unusually well trained. This implies that the sand is conditioned at every turnover, and the average foundry requires about 10 tons of sand in molds and cores to cover the production of a ton of castings. To transport sand by barrows, trucks, or that general type of equipment, from molding floor to mill, and from mill back to molding floor on a scale of say 100 tons of sand per day will cost not less than $1.00 a ton for direct labor and equipment maintenance, and the gangways of the average foundry scarcely would permit such transport even though the cost were warranted by the improvements it led to in the finished product.

If, on the other hand, a foundry were designed for the handling and conditioning of large quantities of sand, then it is almost certain that the sand could be handled at a cost not exceeding $0.25 a ton for direct labor and maintenance of equipment. In a plant so designed it would be a relatively easy matter to determine the comparative advantages of naturally bonded sands, rebonded sands, and synthetic sands. The advantages of any particular type of sand would be first reflected in the cost ledgers, but rather in the cost of castings as a whole than in the costs of any one particular item. In my own experience, however, this criterion would only serve a temporary purpose, for the standard of excellence of castings is being raised pretty continuously. The better sand practice would automatically raise the standard of excellence.

We are using naturally bonded molding sands almost entirely in our various brass and iron foundries. We are using synthetic sands or, more specifically, mixtures of clean silica sand and clay, in some of our steel foundries, and naturally bonded sands in some of our steel foundries. On the whole, I cannot say that we are definitely committed to either type of sand for good and sufficient technologic reasons. We operate a fairly large number of rather small foundry units, each independent of the others so far as material handling problems are concerned; the particular units which I am most concerned with are located in the Albany sand district so that Albany sands are cheaply available to them. We naturally use the naturally bonded Albany sands wherever we find them to be suitable, and they are certainly safely usable for most brass and iron foundry work. For our larger iron foundry dry sand work we are using mainly New Jersey (Millville) gravels, in part because the Albany sands are rather too fine in grain, rather insufficiently bonded, and not overly refractory. In our steel foundries we have had very much better luck with mixtures of clean silica sand and clay than we have had with any naturally bonded silica sands available to us at equivalent cost; the difference has been mainly one of refractoriness.

It is our practice in almost all of our foundry units to use milled facings and milled core sand mixtures, but the bulk of the sand required to make up our molds is taken from floor heaps, and the floor heaps are seldom or never milled when naturally bonded molding sands form the

basis of the heaps. The synthetic sands, I believe, do require milling to make them dependable, and the floor heaps based upon synthetic sand certainly require occasional milling, or at least considerably more rigid preparation than do floor heaps based upon naturally bonded sands. The serious problem in reconditioning sands is less that of milling, or otherwise mixing the sands to insure dependability, than it is one of transportation to and from the sand conditioning apparatus.

H. Frechette: I had intended to speak on the point Mr. Hansen brought up about the development of a eutectic between the silica and the aluminum silicate. That plays quite an important part in the determination of the fracture and also the time factor in the heating. That can't be emphasized too much.

There is a point that I would like to have enlightenment on, and that is the atmosphere within the mold during casting, that is, within the molding sand during casting. Some writers on the subject have pointed out very emphatically that it was an oxidizing atmosphere. I can see the possibility of oxidizing atmosphere in green sand molds where moisture is present, but I fail to see it in any dry sand castings. There are facings, the graphite, there is sea coal, and also the action of the metal itself, it tends to oxidize, and therefore, being of a reducing nature, I would like to know whether the reducing atmosphere is not the real atmosphere of the mold. It has a bearing on the question of the refractoriness of the sand.

D. W. Trainer: I think the Bureau of Mines Station at Columbus sent a questionnaire to several of the representative foundries of the country in regard to whether the atmosphere which the sand had to stand in service was oxidizing or reducing, and I think from that questionnaire they found that the average condition was a reducing condition in the mold.

Chairman R. A. Bull: Are you speaking now of dry sand molds?

D. W. Trainer: They did not state whether the answer to the questionnaire referred to dry sand or green sand molds.

Along the line that Mr. Hansen started, with regard to alumina and silica mixtures, no one knows what you are going to get into when you get more than two components in that system. The biggest system that has been studied up to date is a three component system, but when you get to artificial sands and the refractoriness of artificial sands, you have to be pretty careful of the components that you put into your sand, because when you get into five and six components, you have a proposition that hasn't been handled by anyone as yet.

C. A. Hansen: In studying clays, I have been looking particularly for the upper limits of refractoriness. I do not believe it is possible to add anything to the silica-alumina system that will raise the temperature

limits of that system. Anything we may add, or any impurities likely to be present in clays and sands, like lime, magnesia, iron oxide, titanium oxide, alkali metal oxides, etc., will most certainly lower the refractoriness of silica-alumina mixtures. It is my present impression that the eutectic temperature for pure silica-alumina is pretty accurately placed by Bowen and Grieg at 1540 degrees Cent., and that the impurities found in our commercially available fire clays may reduce this temperature to not much below 1500 degrees Cent.

W. M. Saunders: I would like to call your attention to Mr. Trainer's conclusions in regard to the fluxing of his sands, that the chemical analysis answers to some extent the reason why the sands fused at a much lower temperature, that is, there was a higher percentage of fluxes in those that fused at a lower temperature. It looks as though the chemist could still stay in this business.

A Member: Might I ask Mr. Trainer how those cones were run.

D. W. Trainer: I had great difficulty in making cones of uniform size, length, or in the size of the base, and these cones were not rammed up; they were made when the sand was tempered to almost a mud and placed in a little tin mold and cut out of the mold and then allowed to dry; they were completely air-dried before they were put in the furnace for testing. They were not rammed in a mold.

C. H. Ross: Mr. Trainer made some mention of a government bureau at Columbus receiving replies to a questionnaire concerning the reducing or the oxidizing condition of a mold during pouring and the replies came back in favor of a reducing action. I am wondering if those replies are bold guesses or based upon scientific data. I would say anybody who would, offhand, answer a questionnaire without a good scientific research of about six months is pretty much apt to fire off the trigger too quickly.

D. W. Trainer: You are quite right. I can't understand how they could ever get a questionnaire like that together, but they did. Someone must have had the nerve to offer a solution. They put out this questionnaire and they got some replies on it. What the result of those replies means I don't know.

C. H. Ross: Major Bull's question, "Is it a baked mold or a mold with moisture in it?" is going to have a whole lot of bearing on results.

C. A. Hansen: In the steel foundry, the sand next the casting is usually white and more or less sintered or glazed; this layer is usually very thin. Next follows a layer, perhaps a quarter inch in thickness of black sand, the color probably due to carbon from organic binders. Next follows a more or less red layer, the color no doubt due to oxidation of iron from ferrous oxide to ferric oxide, and this tapers off into the normally colored

backing sand. I do not believe we are justified in saying that the atmosphere in a mold is an oxidizing atmosphere or that it is a reducing atmosphere; it is neither the one nor the other uniformly throughout.

MR. MANN: There is just another point that came up when Mr. Hansen was speaking about eutectics. Now, in most of those eutectics which were found alumina-silicate mixtures, the silica and alumina were ground very finely, and in molding sand practice your silica grains are not fine, and your eutectics, well, you can't sit on them and say, "Well, that is our lowest point."

C. A. HANSEN: Yes you can. Bowen and Grieg determined the melting points of homogeneous products, and I believe their temperature determinations were unusually accurate. The unfortunate thing in the steel foundry is that our sand mixtures need not be homogeneous to sinter. A very small amount of eutectic, readily formed in the clay itself at the temperatures indicated by Bowen and Grieg, is sufficient to cause sintering.

J. H. HALL: I should like to ask Mr. Hansen, in the case of those light cores and heavy castings, if, in his experience, he has seen the sand grains actually fused together so the core couldn't be extracted, or whether there was a steel penetration that caused that sticking together.

C. A. HANSEN: I have seen cores more or less shot through with metal, but I have seen more of them in the iron foundry than in the steel foundry. I have seen silica sand cores in the steel foundry fused so that they looked like Vitrosil—the fused quartz commonly used in laboratory equipment.

J. H. HALL: I asked that question because in my experience when we get a core burned in like that, if you will analyze it, you will find it runs 45 per cent iron.

C. A. HANSEN: Not in ours.

CHAIRMAN R. A. BULL: I have seen the same thing, Mr. Hall.

Metallurgical Control of Foundry Sands

By L. B. Thomas,* Three Rivers, Mich.

Five Important Properties of Molding Sand

There are five characteristics, namely,—bond (clay), permeability, fineness, durability and refractoriness, in which we are interested because they are directly related to the workability of the sand and the quality of mold which it can produce.

Determination of Clay Substance

When we speak of "bond" we refer to the clay content of the sand. We are interested in the per cent of bond (clay) because this is the substance that makes for cohesiveness. We fully realize the significance attached to the word cohesiveness, for it may apply to a fine sand that has but little bond, but on account of the surface tension there is considerable cohesion. When the molder has drops or fall-outs, it is due to the percentage of clay substance, providing that the temper is right and that the mold has been properly rammed. If the clay substance is too high, then we have other complications; the mold may blow, rough surface, etc. So we deem it very important to determine the percentage of clay substance in each and every car of molding sand that enters the plant. This is not sufficient, however, to insure good castings; the sand in the heap must also be tested at regular intervals to determine the percentage of clay substance.

By determining the percentage of clay substance in the new sand as received it is therefore possible to control the heap sand by proper additions of new sand with a known clay content. Every foundry has different conditions. It has been our experience that where sand control work is adopted, it is absolutely necessary to study the existing conditions thoroughly before recommending any change in practice. Very often where one par-

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ticular grade of sand has worked satisfactorily in one foundry, it does not seem to work as well in another. The quality of the sand used in each case may have been very close. We know that there is a reason for it; but you often hear that this sand or that sand does not work satisfactorily. In a case of this kind, a thorough study of foundry conditions must be made and then it is possible to draw conclusions whereby a solution to the problem is at hand.

Temperature of Iron Important

In many foundries there exists considerable differences in the temperatures of the molten iron. In some cases the coke ratio is different and even the bed is higher or lower in practically the same size cupola; that is, the amount of coke above the tuyeres varies in height. This can in most cases be easily accounted for. It is considered best by the operators (cupola) to determine the proper height the bed should be above the tuyeres, and a gauge is made so that day in and day out this proper height can be easily maintained. It is necessary, however, to make sure that the bed is properly fired when the gauge is used; otherwise the bed will be too low, the iron will be sluggish and will not run freely, due to oxidation. Although the cupola may melt quickly, the iron will be on the dull side; in some cases we have found it to be as low as 2100 degrees Fahr. Iron on the dull side will not attack the clay substance nearly as readily as the higher temperature irons with a temperature of about 2350 degrees Fahr.; up in this range it does not take much of an increase in temperature to destroy the bonding qualities of some molding sands. In many foundries, where they are using big cast scrap in their cupola and melting on a high bed, the iron melts slowly but is exceedingly hot; therefore the loss in the bond of the molding sand is greater. Depending also on the size and shape of the castings.

Sand Should Be Tempered Properly

In many foundries the sand is not properly tempered. This is especially true in foundries using the continuous pouring system. It is possible to standardize on the method of tempering

sand so that at all times you can be reasonably sure that the molding sand contains a certain specified percentage of moisture. Where the sand system is of the old style, it is somewhat harder than where you have a definite amount of sand. When water is added to sand in the hot state, just after it passes over the shakeout, it is impossible to get the correct amount of water for proper temper. It is especially bad if this improperly tempered sand is used over again in twenty-five or thirty minutes while the sand is in this hot condition. Sand, carefully examined, that has been subjected to the above severe conditions, will show that some of the sand is entirely dry while other parts are exceedingly wet; also the bending substance appears to be in little lumps, and more appear in some handfuls than others. This is a very bad condition and should be remedied at once as considerable scrap will be caused by this poor tempering of the sand. Metal may wash the dry sand particles from one part of the mold and cause a sandhole elsewhere; then, again, the metal may not lay on the particle of clay substance that has balled up, causing a blowhole.

The best condition for sand tempering is where the sand is allowed to remain in a hopper or bin for at least 24 hours. This will cause the sand to mellow and will be sufficiently cool to insure the best casting and molding condition.

Some sands take more water than others when tempering; this condition is caused by the bonding substance. Just sufficient water must be added to bring back the life of the clay.

By this statement we do not mean that a sand that has been burnt, the silica that was formed by the heat, can be brought back to its original state of plasticity, the hydrated aluminum silicate, but we do mean that the large bulk of the original silicate must have sufficient water added to insure its maximum degree of cohesiveness. This moisture in sand can be easily determined once the temper is correct for that particular grade of molding sand.

In a molding sand containing approximately 25 per cent clay substance we have found that a moisture content of between 7 to 7.5 per cent works very satisfactorily. We have used a rather

crude method for the determination of moisture in molding sands, but it is believed to be accurate enough for foundry control work.

A sample of sand is taken every hour and sent to the foundry sand control room, usually a small room in the foundry that has been turned over to the man in charge of sand testing. To do this work in the chemical laboratory causes more or less friction with the analyst. He will insist that you are getting sand all over the place. Careful as you may be, he will tell you that sand is getting into some of his beakers or flasks and spoiling his determinations. So we have found that the best place for making sand control determinations is in a separate room, especially fitted for this phase of sand testing work.

It has been our practice to take 25 grams of the thoroughly mixed sample of sand to be tested for moisture, received in a glass stoppered bottle, and put it in an evaporating dish for about 10 minutes on a gas hot plate, weighing to constant weight. This has been sufficiently accurate to enable us to keep check on the moisture content of our foundry sands.

Method Used in the Determination of Clay Substance

The method used in determining the clay substance in molding sand is described in detail in Appendix A.

A good molding sand that can be used for general molding must contain at least 20 per cent clay and in most cases can run as high as 30 per cent for maximum clay content.

The one big factor to bear in mind is uniformity of clay content in subsequent shipments. One carload must not be on the low side and the next carload on the high side. It is possible to maintain a uniform product that will not vary more than 1 or 2 per cent in clay substance.

Determining the Permeability Number of Molding Sands

Our tests have all been conducted with a special vent meter, which a sand producing company has placed on the market. This apparatus, together with detailed methods of operation, is described in the section under Appendix B of this paper.

Determination of Fineness

Fineness of sand is determined by sifting 50 grams of dried sand through a nest of sieves; namely, No. 20, 40, 60, 80, 100, 150 and 200 mesh.

The sample is placed on a No. 20 mesh sieve and lightly rubbed with a No. 7 rubber stopper, holding the large end of the rubber stopper in the hand. After sifting on the 20 mesh for two or three minutes, the sand retained on the 20 mesh sieve is carefully weighed and reported as such. The 20 mesh sieve is put to one side, and the process repeated on all the other sieves. This is reported as fineness of sand containing clay substance (see Tables 1 and 2). A fineness determination is also made on the sand after the clay substance is removed. A careful study of the fineness tables will show how the grain size is affected before and after removal of the clay substance.

Wherever possible, sieves of the following sizes should be adopted, namely—Nos. 6, 12, 20, 40, 70, 100, 140, 200 and 270. This standard set of sieves has been recommended* by the American Foundrymen's Association. In many foundries where sand control work is being carried on, the only sieves available for fineness tests are ones that have been discarded by the chemical laboratory. These are not always satisfactory due in many cases to a large jump in sizes between certain sieves in a range where a small variation in grain size means much to the surface of the finished casting.

If the finish of castings is to mean much in the foundry industry, more care will have to be taken in making the fineness test.

It is recommended that a mechanical sieve shaker, the use of which may yield identical results, be used when making fineness determinations.

Purchasing Sand by Designated Number

Before long every sand will be designated not only by a grade number for fineness but also by a class distinction for chemical and physical characteristics.

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*Transactions American Foundrymen's Association, vol. 31, pp. 722-725, 1924.

Table 1

FINENESS TEST OF MOLDING SANDS CONTAINING CLAY BOND

Name of Sand	Per Cent Caught on No. 20	Per Cent Caught on No. 40	Per Cent Caught on No. 60	Per Cent Caught on No. 100	Per Cent Caught on No. 150	Per Cent Through No. 150
D—No. 5	0.00	14.80	23.20	29.20	4.20	27.80
D—No. 7	0.00	11.20	13.40	52.40	10.00	12.60
*D—No. 7	1.80	15.60	14.20	40.60	12.20	15.60
D—No. 7-A	0.00	1.80	6.80	59.00	11.60	20.80
G—No. 4	0.00	27.20	28.20	26.20	5.60	12.80
*G—No. 4	.20	37.74	29.38	20.60	4.08	7.96
G—No. 4-A	.20	31.40	23.00	22.60	5.80	17.00
*G—No. 4-A	.20	28.00	24.40	22.80	4.80	19.80
H—No. 2	.20	11.80	15.60	39.20	14.60	18.20
*H—No. 2	.20	20.00	22.20	40.60	8.00	9.00
H—No. 2-A	.40	8.20	14.20	40.40	13.40	23.40
*H—No. 2-A	.20	8.20	15.00	39.20	11.40	26.00
Hu—No. 2	0.00	2.40	9.40	33.60	30.20	34.40
*Hu—No. 2	.07	9.50	13.40	36.00	9.90	29.60
Hu—No. 2-A	0.00	1.60	6.60	37.00	22.80	32.00
*Hu—No. 2-A	1.20	4.00	8.60	27.60	21.20	37.40
Hu—No. 4	.40	36.60	21.40	23.60	6.20	11.80
*Hu—No. 4	0.00	24.60	20.60	27.40	6.20	21.20
WP—No. 1	.40	12.00	15.20	33.40	14.00	25.00
WP—No. 1-A	.20	11.40	19.60	24.60	12.00	16.20
*WP—No. 1-A	.70	2.90	10.50	49.60	10.80	24.00
WP—No. 2	.20	3.20	9.40	36.40	18.60	32.20

*Burnt.

Table 2

FINENESS TEST OF MOLDING SANDS WITH CLAY CONTENT REMOVED

Name of Sand	Per Cent Caught on No. 20	Per Cent Caught on No. 40	Per Cent Caught on No. 60	Per Cent Caught on No. 100	Per Cent Caught on No. 150	Per Cent Through No. 150
D—No. 5	0.00	17.65	26.75	26.75	5.51	23.45
D—No. 7	0.00	13.27	12.56	48.50	11.87	14.00
*D—No. 7	.85	16.17	14.45	41.10	12.98	14.46
D—No. 7-A	0.00	13.00	13.50	50.00	10.50	13.00
G—No. 4	0.00	19.90	26.85	31.65	6.54	15.10
*G—No. 4	2.00	37.10	25.80	20.90	5.12	9.12
G—No. 4-A	.34	32.64	23.80	25.26	5.70	12.36
*G—No. 4-A	.05	32.00	24.55	23.70	5.45	14.15
H—No. 2	.78	8.41	13.41	38.90	15.10	23.45
*H—No. 2	1.75	13.75	17.75	36.50	11.25	19.00
H—No. 2-A	.37	8.52	14.62	38.02	13.57	25.00
Hu—No. 2	.55	1.93	6.34	32.23	21.21	37.74
*Hu—No. 2	.89	14.80	17.00	30.70	11.62	25.00
Hu—No. 2-A	0.00	1.30	6.00	32.00	19.30	41.40
*Hu—No. 2-A	3.02	6.75	9.53	30.95	16.50	33.25
Hu—No. 4	0.00	34.51	21.70	23.51	6.62	13.41
*Hu—No. 4	.22	37.45	21.15	23.45	5.45	12.30
WP—No. 1	.23	15.35	17.68	32.10	12.55	22.08
WP—No. 1-A	.23	15.60	17.70	32.80	13.27	21.40
WP—No. 2	2.50	3.75	10.68	34.75	15.30	35.25

*Burnt.

Some sands have been tested by dealers for the degree of fineness. The degree of fineness of their respective sands determined, they have divided them into seven grades, according to their fineness as shown in Table 3.

Table 3

FINENESS OF FOUNDRY SANDS

Grade		Fineness Factor
No. 0	Superfine	Above 100
No. 1	Fine	95 to 100
No. 2	Medium Fine	85 to 95
No. 3	Medium	75 to 85
No. 4	Medium Coarse	60 to 75
No. 5	Coarse	45 to 60
No. 6	Extra Coarse	25 to 45

EXAMPLE OF CALCULATION* OF FINENESS FACTOR

Weight of Sand Passing Through Sieves, in Ounces		Number of Mesh of Sieves Used		
55.22	×	100	=	5,522.00
20.89	×	80	=	1,671.00
11.64	×	60	=	698.40
10.57	×	49	=	422.80
1.20	×	20	=	24.00
.06	×	1	=	.06
.42	×	60	=	25.20
100.00				8,363.66

$\frac{8363.66}{100}$ = 83.64 Fineness factor. Sand with a 83.64 Fineness factor would be classed as a No. 3 Medium, nearly a No. 2 medium fine. Any loss is credited to the 60-mesh seive. Any sand that does not go through the 20-mesh sieve is credited to the 1-mesh sieve.

*International Correspondence Schools, *Green Sand Molding*, Part 3, 1699-C.

Size and Shape of Sand Grains

As a general rule the smaller the grain, the finer the surface of the casting.

In casting heavy masses of iron, a mold of very fine sand will not take off the gases fast enough once they can no longer escape through the risers; therefore, the necessity of making tests to determine a sand that will produce a good smooth surface consistent with proper venting qualities. If the matter is complicated by angularity on the part of the grains, it is very easy to see that too hard ramming can quickly spoil a mold made of sharp molding sand, while the rounder grained varieties are not in such danger.

Within the last few years, competition between the large manufacturers has done much to improve the poor surface and appearance of American made castings. Paint heretofore covered a multitude of sins; but since the larger foundries have adopted a rigid method of inspecting castings in the rough the general appearance as well as the quality has been raised to a higher plane, although we have not given the sand problem as much attention as the European foundrymen.

The Belgian foundrymen are noted for their magnificent work the world over. The sand used is highly expensive and is looked after most carefully. The foundrymen of France, Germany and England pay special attention to the preparation of sand with consequent good results.

Durability and Refractoriness

One sand is said to be more durable than another, to possess greater refractoriness, when it stands up longer in the heap without showing signs of going to ashes, although the clay content, permeability, and fineness are practically the same in each case.

We make a shop test on the first carload of every new grade of sand received. In addition to this shop test we conduct a severe burning out test using some simple pattern with no core work.

It is possible to make a very satisfactory shop test when conditions are such as to permit the use of new sand additions to conveyors where the sand is used with jar-squeeze-draw molding machines, especially when using the continuous pouring system and one grade of iron day in and day out, making a uniform size casting with standard steel flask equipment.

Where the sand handling installations are large, it is nearly impossible to obtain accurate results with one carload of molding sand. It may take six or eight loads and as many weeks to determine the several characteristics of a good molding sand in a large installation. Therefore, it is advisable to conduct similar tests on a much smaller scale.

It is also interesting to note that, although two molding sands having similar characteristics will stand up equally as well under the fire test when using a sand ratio of 3.0 parts of sand to 1 part iron, by weight, yet where the inverse ratio is in effect, i. e., where the casting weighs more than the sand in the mold, one sand will burn out more rapidly than another. We will try to explain this condition later on in the text. This will be explained by a study of Table 4, which gives results of sand control tests of

Table 4

CHEMICAL AND PHYSICAL DATA OF SANDS R R S AND W M S BEFORE BURNING OUT TESTS WERE CONDUCTED

A—Chemical Analysis	Sand R R S per cent	Sand W M S per cent
Loss on Ignition	3.44	3.06
Silica	79.45	80.16
Alumina	9.65	9.66
Iron oxide	4.11	3.79
Titania	.48	.22
Lime	1.00	.63
Magnesia	.24	.17
Manganese	.01	.01
Oxide of Potassium	1.25	1.12
Oxide of Sodium	.81	.59
B—Rational Analysis		
Quartz	62.73	64.26
Feldspar	12.24	10.15
Clay substance	18.80	19.76
*C—Smith Vibrator Test**		
Clay substance	45.00	48.00
Silica	55.00	52.00

*E. W. Smith, Trans. American Foundrymen's Association, vol. 31, 1924, pp. 623-630.

two sands, R R S and W M S, both purchased as No. 4 sands. Table 4A lists the chemical analyses of the two sands, 4B the rational analyses and 4C the Smith vibratory bond test results.

The clay bond and silica per cents as determined by the method described in Appendix A are as follows:

	Per Cent in Sample RRS	Per Cent in Sample WMS
Clay substance	29.0	29.0
Silica (by difference)	71.0	71.0

The author has found this method very reliable when using both caustic soda and tannic acid. The fineness tests of these two sands containing clay substance are reported in Table 5A and the fineness tests of the sands with the clay substance removed are reported in Table 5B.

Although these two sands were purchased on the open market for a No. 4 molding sand, it can be readily seen from the data of Table 6 that one is finer grained than the other.

Table 5

A

Fineness Test of Sand Containing Clay Substance Purchased as No. 4 Molding Sand

	R R S per cent	W M S per cent
Caught on 20 mesh sieve	00.60	2.00
Caught on 40 mesh sieve	.80	10.00
Caught on 60 mesh sieve	3.00	25.60
Caught on 100 mesh sieve	18.80	21.20
Caught on 150 mesh sieve	21.80	4.60
Through a 150 mesh sieve	55.00	36.60

B

Fineness Test of Sand with Clay Substance Removed

	R R S per cent	W M S per cent
Caught on 20 mesh sieve	1.40	2.00
Caught on 40 mesh sieve	.80	14.00
Caught on 60 mesh sieve	4.30	24.00
Caught on 100 mesh sieve	19.80	22.85
Caught on 150 mesh sieve	24.30	5.51
Through a 150 mesh sieve	49.40	32.00

Table 6 gives the permeability figures for the two sands before the burning out test was conducted. The first burning out test was made by making molds in a flask 19 inches square with a 51-inch cope and a 6-inch drag. The casting was that of a piston weighing 86 pounds. The mold and casting data are given in Table 7.

Table 6

PERMEABILITY OF ORIGINAL SANDS USING VENT METER

Sample	Moisture, per cent	Cm. Vacuum	Time, seconds	Weight, grams	Permeability No.
R R S	9.00	6.5	26	170	44.5
"	10.50	8.5	30	175	29.5
"	7.50	5.5	23.5	168	58.3
W M S	9.00	7.5	24	175	41.8
"	10.50	7.5	28	175	35.8
"	7.50	5.0	23	170	65.8

The iron was poured from the same stock ladle into a 140 pound shank. Two molds of each sand made, one time pouring one mold containing the special sand from the shank first and

then alternating. Temperatures were checked with an optical pyrometer.

After molds were cast, they were allowed to remain until the castings could be handled with the bare hands. The sand adhering to the castings was scraped off and tempered well with

Table 7

BURNING OUT TEST No. 1 MOLD AND CASTING DATA

Volume of Sand Used per Flask (cubic feet)	2.298
Specific Gravity of Sand, approximately	1.85–2.00
Pounds of Sand per Cubic Inch	.0665
Pounds per Cubic Foot of Sand	115.00
Pounds of Sand in Flask (19" x 19" x 11")	265.00
Weight of Casting (pounds)	86.00
Specific Gravity of Cast Iron	7.20
Weight per Cubic Inch of Cast Iron (pounds)	.260
Weight per Cubic Foot of Cast Iron (pounds)	450.00
Volume of Metal in Flask (cubic inches) 330; (cubic feet)	.1911

water. Both castings were satisfactory from each mold, the appearance of the one made with WMS sand was slightly better.

Following the casting of the piston in the two sands, a clay substance determination was made after the first burning. These determinations gave the following results:

	Per Cent in Sample RRS	Per Cent in Sample WMS
Clay substance	21.8	21.6
Silica	78.2	78.4

The permeability data of the sands after the first burning are given in Table 8.

Table 8

PERMEABILITY OF SANDS AFTER BURNING OUT TEST No. 1 USING VENT METER

Sample	Moisture, per cent	Cm. Vacuum	Time, seconds	Weight, grams	Permeability No.
R R S	9.00	7.00	27	170	39.7
"	10.50	10.00	32	178	23.5
"	7.50	7.50	24	170	41.8
W M S	9.00	4.00	23	175	81.7
"	10.50	4.50	24	180	69.7
"	7.50	3.50	22	175	97.6

The second burning out test was made by using an open top flask 26 inches by 13 inches with a depth of 9 inches. A chill mold was cast in this flask using first one sand then the other,

the chill mold being 20 inches by 11 inches by 6 inches deep. The weight of the chill mold was 259.50 pounds, its volume being 997 cubic inches compared with 2045 cubic inches of sand used.

Following the casting of the chill mold, clay substance determinations were made of the two sands. The resulting data were:

	Per Cent in Sample RRS	Per Cent in Sample WMS
Clay substance...........	16.0	20.00
Silica	84.0	80.00

The permeability test gave the results listed in Table 9.

Table 9

PERMEABILITY AFTER BURNING OUT TEST No. 2 USING VENT METER

Sample	Moisture, per cent	Cm. Vacuum	Time, seconds	Weight, grams		Permeability No.
R R S	9.00	6.50	26	170	....	44.6
"	10.50	7.00	27	175	....	39.8
"	7.50	6.25	26	168	....	46.1
W M S	9.00	4.00	23	170	....	81.7
"	10.50	3.50	22	175	....	97.6
"	7.50	4.00	23	172	....	81.7

Summary of Results of Tests

As was stated in the beginning of this brief outline, we do not feel that a sufficient exhaustive study of the various problems has been made at this writing to arrive at any positive conclusion, nevertheless, a careful examination of the foregoing seems to bring out certain relations which may or may not hold true at all times, but which are, nevertheless, of interest, and may serve to stimulate further study in this direction.

The salient points, therefore, are enumerated in the following general summary:

1. Moisture plays a vital part in comparing the properties of sand, and never should be omitted when reporting comparative tests.
2. Chemical analysis should be made on sands about to be adopted as standards, as very often it is found by determination, to contain harmful amounts of iron, lime, magnesia, sodium and potassium.
3. Each carload shipment of sand should be tested for bond (Clay Substance), permeability and fineness.

4. The amount of the bonding material and the colloidal condition of this material are the important factors on the life of molding sands.
5. As a rule the permeability number of a sand increases with each heat treatment of the sand.
6. The suggested casting method of testing the life of the sand closely approaches foundry practice and is considered the best means of determining the comparative durability.
7. Proper methods should be used to insure a uniform temper of the sand.
8. The balling-up of the clay substance should be eliminated by the use of a fine water spray and the rejection of any reciprocating conveyors.
9. The best results will be obtained with a sand that has been given sufficient time to mellow, and must not be worked while hot and steamy.
10. It is to the interest of the foundry industry as a whole, to find out the durabilities of the sands in common use throughout the United States.

With the above thought in the mind of the reader, it is hoped that this brief resume of work thus far accomplished may contribute something in thought, or actual information, of value to the extensive work now being carried on by the American Foundrymen's Association committee on molding sands, and to such foundries as are engaged in similar work; and that it will point out to others the vital importance of the great problem of the foundry today.

Appendix A

Clay Substance Determination—Shop Control Method

Fifty grams of sand, dried thoroughly at a temperature of about 105 degrees Cent., are put into a 500 c.c. Erlenmeyer flask, and about 250 c.c. water added. The flask is well stoppered and contents shaken for several minutes. The flask is opened, and a stick of sodium hydroxide about 1¼-inch in length is added, the flask is again stoppered and contents well shaken. After shaking the contents of the flask for at least five minutes, the stopper is

removed and the sides of the flask washed down with a stream of water. After sufficient time has elapsed to allow the particles of sand (silica) to settle to the bottom of the flask (usually five minutes is sufficient), the colloidal material present together with any other hydrated minerals which impart to the sand a gelatinous and sticky constituent known as clay substance, is siphoned off, taking care that the grains of sand (silica) in the bottom of the flask are not disturbed.

The process of 5 minutes standing and siphoning is repeated until all the alkali (sodium hydroxide) has been removed by repeated washings. The sand, etc., remaining in the flask is again treated the same as above outlined with one exception, i. e., tannic acid is added in place of sodium hydroxide. One spoonful of dry tannic acid is added to the flask together with 250 c.c. of water and the process of 5 minutes standing and siphoning is repeated until the water remains clear at the end of the five minute period. By this process the clay substance is separated from the grain.

The grains of sand remaining in the flask are washed onto a filter-paper, in a 9 cm. glass funnel and allowed to drain. They are then transferred together with the filter-paper to an evaporating dish and thoroughly dried on a steam plate (bath). When dry, the sand adhering to the filter-paper is brushed off into the evaporating dish containing the bulk of the sand grains.

The difference in weight between the original sample of 50 grams and the weight of the dried grain multiplied by 2×100 equals the per cent of clay substance in the sand.

100.00 per cent—the per cent of silica grain, equals the per cent of clay substance in the molding sand.

Example:

50.00 grams (sample) molding sand taken.

40.00 grams equals weight of silica grains retained on paper.

Difference:

10.00 grams = weight of clay substance removed.

2×10.00 grams = 20.00 grams clay substance per 100 grams of sand. $\frac{20.00}{100} \times 100 = 20.00$ per cent clay substance in the molding sand.

Appendix B

*Vent Meter Method * of Determining Permeability*

Heap or facing sand is tested as tempered for the molders.

Obtain a good representative sample by taking small portions from different parts of the heap. Put this sample, at once, into a two quart pail with close fitting top. Put the top on so as to prevent sand from drying out. Pass the sample twice through a riddle, preferably a No. 8, and return to the pail, replacing the cover.

Next place pedestal, *Y* on the table and put tube *A* down over it. Transfer about 160 grams of sand from the pail to tube, *A* by means of the larger tin scoop received in vent meter box. The sand is placed in this scoop, the scoop held in the left hand in an inclined position over tube *A* and sand raked from scoop to tube *A* with a lead pencil or putty knife, taking care that it flows into tube *A* in a uniform stream and not in chunks. Do not let the scoop touch or jar tube *A* during the operation. Smooth off the upper surface of sand in tube so that it will be level.

Next lift the rammer head *V*** and place tube *A* with its pedestal in the rammer. Lower rammer head *X* on sand gently at the same time adjusting position of tube so that the head slides in the tube without binding.

Place finger of left hand on top of rod above *W* just enough to prevent from lifting. Raise weight *V* till it touches stop *U* and let it drop. Repeat this drop again and again until the weight has dropped three (3) times in all.

Now in order that all your tests be comparative and under the same conditions the length of rammed column should be 2 inches plus or minus 4 per cent. If, by sighting along the top of the support *A-1* you are within the three tolerance limits on gauge *W* the sample is ready for test. If too short, knock out the sample and ram up a new one using more sand this time and vice versa. A small balance for weighing the sand will be of good use, so you can increase or decrease the quantity, if you are making many tests.

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*Method supplied by J. A. Crew, Ayers Mineral Co., Zanesville, O.

**Rammer details same as those recommended by Joint Committee on Molding Sand Research, Trans. American Foundrymen's Assoc., vol. 31, p. 714, 1924.

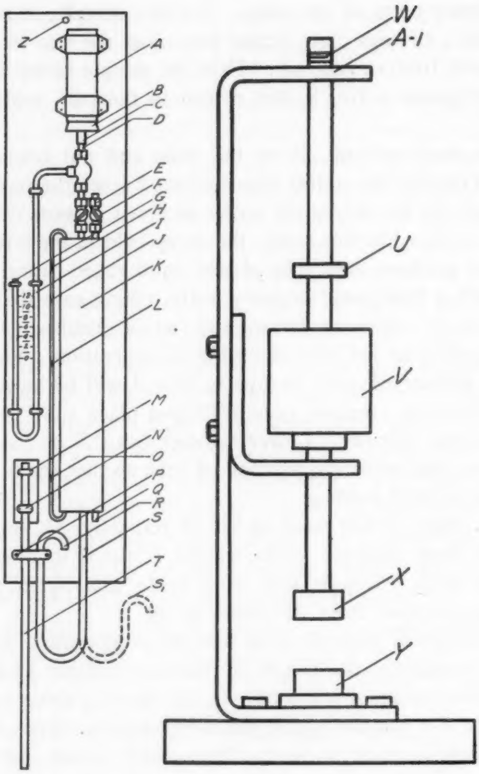

FIG. 1

Note: It is advisable to support the rammer on a cast iron block weighing at least 75 pounds in order to get the anvil effect.

The above operation of ramming should require not more than two minutes.

Next lift rammer to clear tube *A*, remove tube from the pedestal, insert rubber stopper *B* in end of tube, place the tube in vent meter as shown on blue print connecting to tube *D* by rubber connection *C*. (If the tube *D* is moistened a little with water the rubber connections slip on more easily.)

To Determine Permeability by the Pressure Method

Close valve *E* and open valve *F*. Place finger over discharge outlet S-1 and turn on water so as to fill tube *K* through inlet *Q*, filling slowly and stopping when reservoir is just short of full, as shown on water gauge *J*.

Shut off faucet tight, close valve *F* and remove finger from discharge outlet *S-1*. Then open valve *E* and watch manometer *I*. The water level in the right leg of the U tube will rise; note this level as indicated on the scale. The tighter or less permeable the sand is, the higher the water level will go and vice versa. The reading on the scale thus obtained is a measure of the permeability of the sand by the pressure method and is good for the daily checking of sand heaps.

To Determine Permeability by the Formula Method

This method is slower than the pressure method but should be used when comparing results with other outside concerns. Connect the rubber tube with its curved discharge to outlet *S-1*, as shown in the dotted lines on blue-print. Also fasten rod *T* in holders *M* and *N* as shown. Then proceed as in the pressure method, regulate the pressure on *U* tube by moving discharge up or down on rod *T* until the water level is exactly on one of the pressure lines of the scale. To measure the time required for the water level in gauge *I* to drop from the starting point *H* to end point *L*, a stop watch graduated in minutes and tenths is advisable.

The venting power or permeability of the sand is then calculated by multiplying the time in minutes and tenths of minutes by the pressure used and dividing this product into 125.3.

By the formula: $\frac{125.3}{T\,P}$, where T is time in minutes and tenths of minutes, and P is the pressure in cm. of water as shown on the manometer *I*.

For very open sands a pressure of 1 or 2 is best to use, while for very tight sands the pressure can be carried as high as 30 or more.

The above test can be made in two minutes, always check the zero on manometer *I* before starting test and before connecting up tube *A*.

To Test New Sands

In order to accurately determine the venting power or permeability of new sand it is best to dry out a good representative sample and divide into several portions. Temper each portion to a different degree depending whether the sand is heavily bonded or lightly bonded. After tempering, riddle once through a No. 8 (use a No. 4 if gravelly sands are used), place in a pail, put cover on tight and let stand for a few hours in a pail to equalize the temper. Then test as directed for heap sands.

This test will show how much the sand closes up with excessive temper and will show at what temper it has the most open structure after ramming. Sands differ a good deal from each other in this respect.

For lightly bonded sands it is well to temper different portions to 6, 8, 10 and 13 per cent moisture, respectively, while for heavily bonded sands, 8, 10, 12 and 14 per cent is recommended. For tempering in this way we recommend the use of an inexpensive trip balance with set of metric weights for weighing the dry portions and a glass tube graduated in metric system for accurately measuring the tempering water to any percentage desired.

The Grading of Molding Sands

By C. A. Hansen, Schenectady,[1] N. Y.

Introduction

Molding sands differ from one another in the following important respects:

A. Refractoriness of grain—determined mainly by mineral character.

B. Bonding substance—in natural sands, the refractoriness, plasticity, and general character of the "clay substance."

C. Grain size—the average "diameter" of the sand grains.

D. Uniformity of grain—the range and distribution of grain sizes.

E. Shape of grain—spherical, rounded, or sharply angular.

F. Content of bond substance.

G. General uniformity—in respect to variation as between successive shipments.

The above characters collectively determine the usefulness of a sand for any specific phase of foundry activity.

Molding sands are selected products. The process of selection has been a more or less empirical one of trial and error, but it has nevertheless functioned to limit the production of sands in general commercial foundry use to relatively few well recognized districts. The sands from a given district, in the sense here considered, have a common geologic origin which leads to reasonably consistent similarity in the mineral character of the sand grains and bonding substance, and, to a somewhat less marked extent, similarity in respect to shape and uniformity of grain. Insofar as these characters impose practical limitations, as in refractoriness, for example, they are reasonably well known to foundrymen generally.

But from any one of the well known sand producing districts, sands are shipped commercially in a fairly wide range

[1] General Electric Co., Schenectady, N. Y.

of average grain sizes, or fineness grades, and with a fairly wide range of bonding substance. Such sands can be described with an accuracy reasonably sufficient to producer, vendor and consumer in terms of "District of Origin," some logical "Grain Size Index" or fineness grade, and some logical "Bond Index." In effect, sands are regularly sold on a basis equivalent to this —a No. 2 strong Albany sand is quite definitely understood to be from the Albany district, its fineness is indicated by the No. 2, and it is relatively high (for the Albany district) in effective bonding substance.

The writer believes that the Albany grading scale, as applied to fineness of grain, is the oldest and most firmly established of the many grading scales in current use. So far as he knows, no clear definition of this scale has been published. C. M. Nevin[2] reported a large number of screen analyses of graded Albany sands and endeavored to show the relations between the grade numbers, the distribution of grain sizes, and the physical properties of the corresponding sands, but he did not attempt to develop a rational grading scale nor to develop the conclusion that the Albany grading scale was essentially rational.

As a matter of fact, the Albany grading scale originally depended solely upon the sense of touch; it is still in effect upon this original basis; and the conditions under which Albany sands are produced are such that the sense of touch will probably continue to be the basis of all grading in the district. The same conditions exist in most of the sand producing districts with which the writer happens to be familiar. In spite of its crude basis, the Albany grading scale is a quite definite one to those very few individuals of long experience who supervise the production and loading of the major portion of the Albany sands. The scale becomes less and less definite as the sands recede from these supervisors until, at the extreme end, among foundrymen, the scale is a rather hazily indefinite affair. As an example of this—the most competent of the Albany district graders recognize no grade finer than No. 0, nor coarser than No. 3½ as existent in their field, but they will bill a shipment of No. 0 sand

[2] Nevin, C. M., *Notes on the Grading of Sands with Special Reference to Albany Sands.* Trans. A. F. A. vol. 32, pt. 2, 1925.

as No. 000, or a shipment of No. 3 sand as No. 5 to foundrymen who have peculiarly individual conceptions of grade numbers.

The writer will here attempt to describe an interpretation of the Albany grading scale which he has developed and used in regular routine work over a period of two years with quite satisfactory results, more particularly for the purpose of providing a logical basis for the orderly classification of sand records.

He will further try to show that this grading scale is as readily applicable to other than Albany sands, with the purpose of promoting a standard sand nomenclature which will enable foundrymen generally to more readily understand one another.

Methods of Determining Grain Size

The sense of touch is reasonably accurate when applied to the determination of the relative fineness of sands; very little experience is necessary to enable one to distinguish correctly between sands differing by a half Albany grade in fineness when the sands are placed side by side for direct comparison. But it requires long and continuous experience to develop anything approaching accuracy in judging the absolute fineness of sands, and it is impossible to convey this individual experience to others. It is therefore essential that some more finite method of determining absolute fineness be applied in order that the fineness scale shall be fixed or stabilized and thus become generally useful.

The only commonly accepted methods of determining the fineness of sands involve mechanical classification by means of arbitrarily selected screens. The fundamental basis upon which American standard screens were designed was proposed by Prof. Rittinger [3]—a systematically graduated series of square mesh openings such that the area of any one opening was twice that of the next finer one.

The Tyler company developed a series of screens embodying the Rittinger proposal, basing the series on the No. 200 screen (linear mesh opening 0.0029 inch or 0.074 mm.) which was widely used for the testing of cement. The Bureau of

[3] Proceedings A.S.T.M. vol. 13, 1913, page 1068. See also W. S. Tyler Company (Cleveland) Catalog No. 48.

Standards [4] developed a similar series from the same base screen. The successive mesh openings of the two screen series are alike, and both agree with the Rittinger formula to within accepted tolerance limits. But the two series differ in respect to wire diameters, and screens of like mesh opening do not, therefore, have the same number of meshes per linear inch. Furthermore, the screens are known by their respective number of meshes per linear inch and there is no constant relation, direct, inverse, or exponential, between the screen numbers and the respective mesh openings. This has led to needless confusion, since the number of meshes is relatively much less important than the size of the opening. The screen numbers in neither case constitute a rational scale and this has led to error in methods of calculating fineness indices which make use of the screen numbers as factors.

The objections to the above mentioned screen numbers can readily be avoided by simply numbering the screens serially, since it follows from the Rittinger formula that such serial numbers will constitute a rationally uniform scale. It so happens that the serial numbers shown in the left hand column of Table No. 1 are particularly adaptable to molding sands. The zero of this scale coincides with the dividing line between "clay substance" and "pan material." [5] The numbers 1, 2 and 3 correspond very closely to the average fineness of Albany Sand Grades 1, 2 and 3, respectively.

The Joint Committee on Molding Sand Research recommended a series of screens [6] for the testing of sands, a selection from the Bureau of Standards series. Unfortunately this particular selection does not constitute a uniformly graduated series, as is evident from Table No. 1. The rhythm of the Rittinger series was sacrificed for the sake of some slight economy in the pur-

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[4] The Bureau of Standards interposed a screen between each pair of the Rittinger series, as proposed by Prof. R. H. Richards. The Richards series is more finely graduated than is necessary for molding sand tests and it need not be further considered here.

[5] When sands are washed in the manner recommended by the American Foundrymen's Association for the removal of "clay substance," the coarsest material included in the clay substance fraction is approximately 1.0 mil in diameter. Similarly, the finest grains in the "pan material" (—270, —300 mesh) are also approximately 1.0 mil in diameter. These estimates are based upon the determined settling rates in water. C. M. Nevin, at Cornell University, obtained closely agreeing determinations by means of the microscope and ocular micrometer.

[6] Transactions American Foundrymen's Association, vol. 31, p. 725, 1924.

chase of screens. This lack of rhythm has led to frequent error in the interpretation of screen analyses, and it has operated to conceal a fairly simple, symmetrical distribution of grain sizes which definitely characterizes a very large majority of all molding sands. It is this symmetry which the writer has used during the past two years as a basis for grading sands, and it is this same symmetry which makes for the rationality of various methods of calculating "fineness indices" which will be discussed later.

Table 1

COMPARISON OF TYLER COMPANY AND BUREAU OF STANDARDS SERIES OF SCREENS*

Rittinger Scale or Screen Serial Number (N)	Usual Screen Numbers or Nominal Meshes per Linear Inch of Screen: Tyler Company	Usual Screen Numbers or Nominal Meshes per Linear Inch of Screen: Bureau of Standards	Linear Mesh Openings in Mils (thousandths of an inch): Rittinger Formula Requirement***	Linear Mesh Openings in Mils: Tyler Company	Linear Mesh Openings in Mils: Bureau of Standards	Product of Usual Screen Numbers and Mesh Openings**: Tyler Company	Product of Usual Screen Numbers and Mesh Openings**: Bureau of Standards	Settling rates in water in feet per second for largest grains passing Tyler screens
8	3	3	261.0	263	265	789	795	......
7.5	4	4	184.5	185	187	750	748	1.002
7	6	6	130.5	131	**132**	786	792	0.872
6.5	8	8	92.2	95	93.7	760	750	0.756
6	10	**12**	65.3	65	**66.1**	650	793	0.608
5.5	14	16	46.4	46	46.9	624	750	0.520
5	20	**20**	32.7	32.8	**33.1**	656	662	0.408
4.5	28	30	23.2	23.2	23.2	648	696	0.308
4	35	**40**	16.3	16.4	**16.5**	574	660	0.226
3.5	48	50	11.6	11.7	11.7	557	585	0.164
3	65	**70**	8.2	8.2	**8.3**	533	581	0.114
2.5	100	**100**	5.8	5.8	**5.9**	580	590	0.0764
2	150	**140**	4.1	4.1	**4.1**	615	574	0.0496
1.5	200	**200**	2.9	2.9	**2.9**	580	580	0.0310
1	300	**270**	2.04	2.1	**2.1**	620	567	0.0196
0.5	...	...	1.44	...	...	...	...	0.0162
0	...	...	1.02	...	...	...	...	0.0096

*Figures in bold face indicate screens advocated by the Joint Committee on Molding Sand Research.
**Lineal opening = 1.02×2^{n}.
***Note lack of constant relation between screen number and mesh opening.

In regard to the manner in which screens shall be used in making sand analyses, the recommendations of the Joint Committee on Molding Sand Research are clear and they are sufficiently complete. The screen series should be changed to make it a uniformly graduated series, either by adding four screens to make the ratio of successive mesh openings 1.41, or by dropping two screens to make the ratio of successive mesh openings 2. If screens are carefully selected and carefully used, the simpler screen series is amply accurate for all practical purposes.

Screens, however, are generally abused in such manner as to destroy the initially uniform weave, and when this uniformity of weave is destroyed the screens are very far from being precision tools. The greater the number of screens, the less important becomes one or more inaccurate screens in the series and, furthermore, the inaccurate screens are conspicuously indicated in the results obtained, so that they can be weeded out and discarded.

Table 2

FRACTIONAL AND CUMULATIVE SCREEN ANALYSES, DORCHESTER (N. J.) SILICA SAND

Rittinger Screen Numbers	Weight percentages — Fractional			Weight percentages — Cumulative		
	Tyler screens	AFA screens	Ratio 2 screens	Tyler screens	AFA screens	Ratio 2 screens
+7	0.01	0.01	0.01	0.01	0.01	0.01
6.5	0.03	....	....	0.04	....	....
6	0.13	0.16	0.16	0.17	0.17	0.17
5.5	0.48	....	....	0.65	....	....
5	1.48	1.96	1.96	2.13	2.13	2.13
4.5	5.52	....	....	7.65	....	....
4	15.55	21.07	21.07	23.20	23.20	23.20
3.5	30.23	....	....	53.43	....	....
3	26.57	56.80	56.80	80.00	80.00	80.00
2.5	13.35	13.35	....	93.35	93.35	....
2	4.45	4.45	17.80	97.80	97.80	97.80
1.5	1.55	1.55	....	99.35	99.35	....
1	0.47	0.47	2.02	99.82	99.82	99.82
0.5 } 0 }	0.18	0.18	0.18	100.00	100.00	100.00
Total above	100.00	100.00	100.00	100.00	100.00	100.00
Clay substance	0.36	0.36	0.36	0.36	0.36	0.36

The Interpretation of Screen Analyses

Screen analyses serve to determine the distribution of grain sizes of sands. There are two generally used methods of tabulating the analytical data obtained, the fractional method commonly used by American foundrymen, which involves tabulation of the weight percentages trapped between each successive pair of screens, and the cumulative method commonly used by European foundrymen and by mining engineers the world over, which involves tabulation of the cumulative percentages coarser than the successive mesh openings. The two methods are illustrated in Table No. 2. They are equally legitimate when properly used, and choice between them is mainly a matter of personal opinion.

A great many methods have been used to show the distribution of grain sizes graphically, i. e., by means of plotted curves, and much too large a proportion of these have yielded grossly distorted pictures of the distribution they were intended to portray. The errors have been due to improperly selected screens, to improperly selected dimensional scales, and to improper regard for the limitations of screen data. Graphs that are correct,

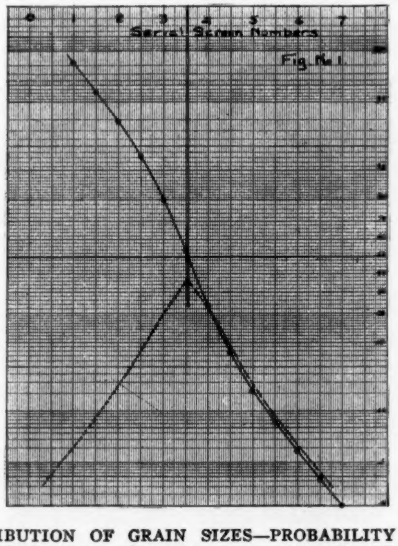

FIG. 1—DISTRIBUTION OF GRAIN SIZES—PROBABILITY CO-ORDINATE SYSTEM PROPOSED BY WHIPPLE—SOLID CURVE PLOTTED FROM CUMULATIVE WEIGHT PERCENTAGES; THE BROKEN CURVE SHOWS THE DISTRIBUTION OF GRAIN SIZES AS DERIVED FROM THE CUMULATIVE PLOT

within the limits of the analytical method, are shown in Figs. 1, 2 and 3. The solid curves in Figs. 1 and 2 are plotted from cumulative percentages; the cumulative datum point establishes a definitely fixed relation between weight and dimension, and the cumulative plot involves but one assumption that can affect its accuracy, viz., that the distribution is continuous, that all intermediate grain sizes are present in the sample. The fractional

data are less acceptable as a basis for plotting curves; the datum point merely indicates that a definitely determined weight of material is finer than one, and coarser than the other of the two limiting mesh openings; the distribution curve must lie between the determined limits, but its exact position is rather difficult to determine. In Fig. 3, the limiting curves are shown by broken lines, and the estimated distribution curve is indicated by the solid curve.

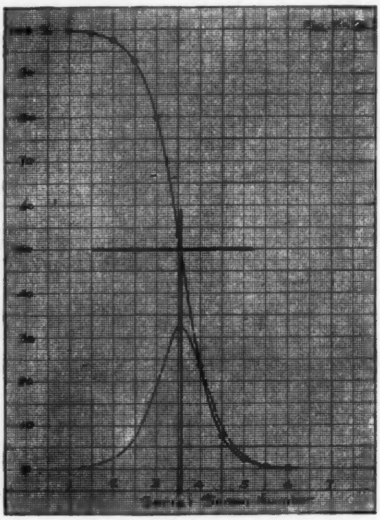

FIG. 2—DISTRIBUTION OF GRAIN SIZES—SAME AS FIG. 1 EXCEPT THAT A MORE READILY AVAILABLE TYPE OF CO-ORDINATE PAPER IS USED

The co-ordinate system used in Fig. 1 was proposed by Whipple[7] for the plotting of "probability" functions and it seemed to the writer that the distribution of grain sizes in sands should properly come within the scope of "probability laws." Sands are deposited in nature subject to classification by wind and water, conditions that are not sharply selective, but still favor the depo-

[7] Whipple, G. C., *The Element of Chance in Sanitation,* Journal of Franklin Institute, vol. 182, 1916, pp. 205-227.

sition of a specific grain size in any particular bank; the relative frequency of deposition of other grain sizes should diminish fairly regularly as the deviation from the favored grain size increases, and the distribution of grain sizes should be more or less symmetrical with respect to the favored grain size. If the assumption is perfectly true, then with Whipple co-ordinates and correctly selected dimensional scale, a screen analysis should plot as a straight line, the slope of the line indicating the exactness of the classification or uniformity of grain size. With the dimensional scale selected, the curve should take very nearly the

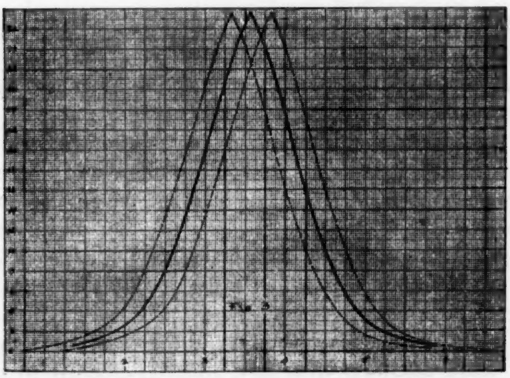

FIG. 3—DISTRIBUTION OF GRAIN SIZES—THE BROKEN CURVES SHOW THE LIMITS WITHIN WHICH THE TRUE DISTRIBUTION OF GRAIN SIZES MUST LIE, THE SOLID CURVE IS THE ESTIMATED DISTRIBUTION

shape shown—a rather weakly flexed curve which may be quite accurately drawn from relatively few determined datum points. The broken curve in Fig. 1 is the distribution curve derived from the cumulative plot. While this co-ordinate system is peculiarly well adapted for use in plotting screen analyses, several more readily available type of co-ordinate papers may be used to yield the same end results; Fig. 2 is but a single example of them.

A fairly rational "Fineness Index" may be derived from the cumulative curve; half the sand (by weight) is certainly finer,

and half coarser, than 3.55 Rittinger scale units. See Figs. 1 and 2. The 50 per cent dividing line of a "probability function" should be its axis of symmetry and it is known as the "Median." We may say that the "Median Index" of this particular sand is 3.55. Another fairly rational "Fineness Index" may be derived from the distribution curve (Figs. 1 and 2); one particular grain size contributes more than any other to the total weight of the sand, that grain size corresponding to the apex of the distribution curve; this may be called the "Predominant Grain Size." This, also, is 3.55 Rittinger units for the sand illustrated; the "Median Index" and "Predominant Grain Size" are alike, as they should be according to assumption.

Still other "Fineness Indices" may be calculated by purely arithmetical methods without recourse to the plotting of curves, but these methods all involve the conception of curves and they are correct only in so far as they are consistent with this conception. If we have to find the average height of an irregular curve above a base line, it is necessary to draw the curve to scale both vertically and horizontally. The average height of ordinate, equally spaced along the base line, is calculated from the measured heights of the individual ordinates, or the area enclosed by the curve is determined and this is divided by the length of the base line to give average height.

Of such arithmetical methods, the Scranton method has received more attention than any other as applied to molding sand. The percentage (by weight) of sand trapped in each screen interval is multiplied by a size factor; the products are added together and divided by the total weight of sand to yield a "Fineness Number." In effect this is equivalent to determining the area enclosed between curve and baseline and dividing by baseline length to obtain average height. But when the screen series recommended by the Joint Committee on Molding Sand Research is used, the ordinates are not uniformly spaced along the baseline, and the factors used[8] do not constitute a uniform

[8] A. A. Grubb suggested the factors used by the writer in calculating Grubb-Scranton "Fineness Numbers":

Screen Interval	Factor	Screen Interval	Factor
—6 +12	5	—100 +140	100
—12 +20	10	—140 +200	140
—20 +40	20	—200 +270	200
—40 +70	40	—270	300
—70 +100	70		

scale. The results obtained are therefore open to criticism, although they actually work out to be sufficiently accurate for practical foundry purposes.

The methods shown in Table 3 are essentially the same as the Scranton method, but they avoid the errors above mentioned. By selecting uniform screen intervals, the ordinates to be averaged are uniformly spaced, and by substituting the Rittinger numbers as "factors" the base line is laid out to a uniform scale.

Table 3

CALCULATION OF AVERAGE FINENESS OF DORCHESTER (N. J.) SILICA SAND FROM FRACTIONAL ANALYSES

Tyler screens, 1.41 Ratio						Simplified screen series, 2.0 Ratio					
Dimension						Dimension					
Limits	Average		Weight		Product	Limits	Average		Weight		Product
7.5—7.0	7.25	×	0.01	=	0.073	8—7	7.5	×	0.01	=	0.075
7.0—6.5	6.75	×	0.03	=	0.203						
6.5—6.0	6.25	×	0.13	=	0.813	7—6	6.5	×	0.16	=	1.040
6.0—5.5	5.75	×	0.48	=	2.760						
5.5—5.0	5.25	×	1.48	=	7.770	6—5	5.5	×	1.96	=	10.780
5.0—4.5	4.75	×	5.52	=	26.120						
4.5—4.0	4.25	×	15.55	=	60.088	5—4	4.5	×	21.07	=	94.815
4.0—3.5	3.75	×	30.23	=	113.362						
3.5—3.0	3.25	×	26.57	=	86.352	4—3	3.5	×	56.80	=	198.800
3.0—2.5	2.75	×	13.35	=	36.712						
2.5—2.0	2.25	×	4.45	=	10.013	3—2	2.5	×	17.80	=	44.500
2.0—1.5	1.75	×	1.55	=	2.713						
1.5—1.0	1.25	×	0.47	=	0.587	2—1	1.5	×	2.02	=	3.030
1.0—0.0	0.50	×	0.18	=	0.090	1—0	0.5	×	0.18	=	0.090
Totals.........			100.00		347.656				100.00		353.130
Average fineness ...			$\frac{347.656}{100.00}$	=	*3.48*				$\frac{353.130}{100.00}$	=	*3.53*

In one case, the Joint Committee on Molding Sand Research screens have been augmented to make a uniform Rittinger series and the calculated index is 3.48; in the other case the Joint Committee's screens have been diminished by leaving out the 100 and 200-mesh screens to make a simplified series with a uniform ratio of 2, and the calculated index is 3.53.

An equivalent arithmetical method which is still simpler, but rather more difficult to explain, may be carried out as follows: Add together the cumulative percentages as set down for the simplified screen series, omitting to add the percentage set down against the No. 0 screen (pan material). Divide this total by 100 and add 0.50 to the quotient. For the sand covered by Table

No. 3, the sum of the cumulative percentages is 303.13; divide by 100 and add 0.50 and the index is 3.53. In proceeding in this manner, each fraction is added into the final total N times, N being the Rittinger number of the limiting screen and therefore 0.50 less than the proper factor. The 0.50 error affects all fractions alike, hence the final quotient may be shifted back into proper position by adding 0.50. This method is particularly simple where all screen analyses are tabulated cumulatively, as are the writer's, and a little inspection will disclose that it carries with it a triple check on accuracy.[9]

It will be noted that the calculated indices agree with one another and they also agree with the indices determined graphically. This appears to be true for practically all natural sharp sands and approximately true for all natural sands. Data covering several sharp (clay free) sands are shown in Table No. 4. In general, the distribution of grain sizes in natural sands is reasonably symmetrical with respect to the "Median" and the "Median" agrees approximately with the "Predominant Grain Size." There is a great deal of evidence to indicate that a large fraction of the material in naturally bonded sands known as "clay substance" is really finely divided sand rather than effective bonding material. This is particularly true of sands that are so fine that more than half their weight is beyond the capacity of our finest screens to classify. Graphic methods, as applied to these very fine sands, are rather unsuitable as a basis for exact grading, since the personal equation enters to too large an extent in extrapolating beyond the range of easily determinable finenesses.

Similarly, graphic methods, although interesting and valuable, are not suitable as a basis for the exact grading of deliberate mixtures of essentially dissimilar sands. Such mixtures are very seldom, perhaps never, found in nature, but they are fairly common in the foundry and they are quite frequently prepared by sand producers—blending over bonded fine sands with coarser

[9] Since the Joint Committee on Molding Sand Research has distinguished between "sand" and "clay substance," the writer confines discussion of grain size to the "sand" and all screen analyses are based upon sand, ex clay, as 100 per cent. The modification necessary to accommodate the method to a sand plus clay basis of 100 per cent is reasonably obvious.

Table 4

Screen	Sand: H-98	H-35	H-99	H-116	H-103	H-X	H-34	H-117	H-28	H-37	H-54	H-100	H-93
+6	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0
+5.5	0.0	1.6	0.0	0.2	0.0	0.0	0.3	0.0	0.4	0.5	0.0	0.0	0.0
+5.0	0.5	7.7	0.1	1.1	0.1	0.1	2.0	0.1	1.2	0.9	0.0	0.0	0.0
+4.5	31.0	24.0	4.6	9.7	3.0	3.2	6.5	0.3	3.0	2.0	0.0	0.1	0.0
+4.0	97.8	50.0	40.2	34.7	22.8	20.0	17.0	1.0	7.0	5.2	0.0	0.1	0.0
+3.5	100.0	81.8	69.8	62.7	60.4	53.4	38.4	14.6	17.3	21.2	0.3	0.1	0.0
+3.0	....	96.2	85.4	84.4	89.5	80.0	68.5	67.9	54.4	49.3	4.6	0.4	0.3
+2.5	....	99.0	92.9	97.1	99.2	93.4	85.0	93.7	87.0	69.0	23.2	8.9	2.6
+2.0	....	99.5	97.9	99.5	99.8	98.3	94.6	97.9	98.3	81.9	52.5	48.9	10.3
+1.5	....	99.7	99.6	99.8	99.9	99.5	98.2	98.7	99.4	91.1	82.8	82.8	27.7
+1.0	....	99.8	99.9	99.9	100.0	99.9	99.5	99.5	99.6	95.7	95.3	95.3	49.7
+0.0	....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Clay	0.0	0.0	0.0	0.4	0.0	0.4	0.0	1.2	0.3	0.7	0.0	0.0	6.0
Rittinger Index:	*4.35	4.05	3.70	3.70	3.63	3.49	3.30	3.12	3.09	2.84	1.99	1.94	1.20
	**4.48	4.03	3.72	3.70	3.60	3.48	3.32	3.16	3.11	2.83	2.02	1.95	1.10
Median Index:	4.35	4.00	3.82	3.75	3.62	3.55	3.32	3.15	3.07	2.97	2.05	1.95	0.95
Grubb-Scranton Index:	30.2	30.9	39.7	38.9	39.0	44.9	54.1	53.3	57.9	80.3	125.7	132.5	228.7

Key to Analyses

H-98 Flint Shot—Ottawa, Ill. Screened.
H-99 Flint Shot Jr.—Ottawa, Ill. Screened.
H-100 50 Mesh Banding Sand—Ottawa. Screened.
H-X Run of Mine—Ottawa, Ill. Natural.
H-35 Core sand—Utica, N. Y. Natural.
H-34 Core sand—Utica, N. Y. Natural.
H-37 Core sand—Luzerne, N. Y. Natural.
H-93 Core sand—Luzerne, N. Y. Natural.
H-54 Core sand—McConnellsville, N. Y. Natural
H-28 Silica sand—Cedarville, N. J. Natural.
H-103 Silica sand—Millville, N. J. Natural.
H-116 Silica sand—Millville, N. J. Natural.
H-117 Silica sand—Millville, N. J. Natural.

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*Full screen series. **Diminished or 2 Ratio screens.

weakly bonded sands. For such mixtures, the "Median Index" loses significance, in that it is no longer an axis of symmetry; the "Predominate Grain Size" loses significance in that there may be several equally prominent grain sizes. Even arithmetically developed fineness indices become somewhat arbitrary, but they possess the merit of being more strictly definable so that all who apply the formulated method of calculation will at least all reach the same conclusion.

Under the circumstances, the writer proposes as a practicable "Fineness Index" the Rittinger Index as calculated in Table 3—from data determined with the simplified (2 ratio) screen series.

The Relation Between Rittinger Indices and Albany Grade Numbers

In Table 5 are arranged various data for approximately 100 Albany sands, no two of them known to originate in the same bank.

When these sands are regrouped according to producers' grade numbers as taken from shipping memoranda, the average "Fineness Index" for each grade group is found to be as indicated by the points in Fig. 4. The relation between Rittinger index and grade number is seen to be approximately linear for grades 0 to 3, inclusive. The Rittinger index for any given sand is a finite number; grade inherently implies a limited range of fineness and grades must necessarily overlap so long as sands continue to be graded commercially by purely touch sense. Sixty per cent of the sands in each producers' grade group fall within the fineness limits indicated in Fig. 4. Neither the average fineness, nor the fineness range, shown in Fig. 4 is essentially altered when the analysis is extended to cover an additional 214 sands for which data have been accumulated since Table 5 was prepared (about a year and a half ago).

It is to be noted that grades 00 and 3½ are essentially identical with grades 0 and 3—both as regards average fineness and range of fineness. As a matter of fact, there are no commercially available sands in the Albany district finer than No. 0 or coarser than No. 3 as these grades are defined in Fig. 4; grades

Table No. 5—*Albany Sands classified into "Rational Grades" by the Median Index method.*

	Screen Analyses*												Rittinger Indices			Grades Applied by Producers								
Screen No.	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	Clay	Median Index, from plotted curves.	Calculated, Augmented screen series. (1.41 Ratio.)	Calculated, Diminished (2 Ratio) screen series.	Grubb-Scranton Fineness Number.	C. M. Nevin's Grade Number (A. F. A. Trans., 32, 2, 182).	Producer's Grading, Shipping Memos.	Graded by Connor or Matthiessen, Whitehead Bros. Co.	Graded by George Reed, Charles Pettinos Co.	Maximum Green Permeability.	Maximum Permeability, Baked Cores.	Maximum A. F. A. Green Bond.	Maximum Green Compressive Strength Lbs. per sq. in.
Mesh Tyler	10	14	20	28	35	48	65	100	150	200	300	....												
Mesh A. F. A.	12	....	20	....	40	....	70	100	140	200	270	....												
**N-220	2.4	....	4.8	....	31.0	**63.0**	79.2	84.1	86.4	88.4	91.9	11.3	3.7	....	**3.46**	65	3	3	....	....	143	....	131	....
N-218	2.4	....	5.0	....	23.5	**63.0**	82.8	86.4	88.2	89.8	92.9	10.6	3.7	....	**3.45**	62	3	3	....	....	190	....	132	....
†H-40-C	1.9	....	5.6	....	26.7	**60.5**	74.7	83.7	87.7	91.3	93.6	10.7	3.6	....	**3.40**	....	....	4	....	....	110	165	....	5.2
††W-3-M	1.9	3.3	5.5	10.5	25.3	**59.9**	74.4	79.5	82.5	85.1	88.3	9.5	3.6	3.32	**3.28**	....	....	3	3	....	122	....	134	....
W-3.5-O	2.0	3.1	4.8	9.4	23.8	**58.0**	78.0	84.5	87.4	89.6	91.7	8.6	3.6	3.41	**3.38**	....	....	3.5	3.5	....	180	....	110	....
W-3-O	1.8	2.8	4.8	8.5	23.7	**58.0**	79.7	84.0	86.5	88.4	91.0	9.4	3.6	3.40	**3.38**	....	....	3	3	....	164	....	135	....
H-40-545	5.1	....	11.8	20.0	33.6	**54.0**	75.3	83.1	87.8	91.3	93.3	3.7	3.6	....	**3.57**	....	....	4	....	....	140	165	....	7.3
H-10	1.9	....	6.3	....	31.0	**53.4**	76.5	79.9	81.8	88.0	90.6	10.7	3.6	....	**3.38**	....	....	3.5	3.5	3	97	....	133	4.4
H-8-543	1.8	....	6.0	12.5	24.1	**53.0**	82.8	87.1	89.1	91.1	92.5	10.6	3.6	3.47	**3.46**	....	....	3.5	....	....	152	185	....	5.7
W-3.5-M	2.9	5.0	9.7	18.0	32.3	**53.0**	65.7	70.6	75.0	78.2	82.8	11.7	3.6	3.22	**3.18**	....	....	3.5	3.5	....	35	....	210	....
N-219	2.9	....	5.8	....	21.0	**53.0**	82.2	88.4	90.8	92.6	94.6	9.2	3.55	....	**3.46**	58	3	3.5	....	....	240	....	106	....
N-217	3.2	....	7.1	....	29.3	**50.5**	67.1	72.3	75.3	78.2	85.9	14.6	3.5	....	**3.18**	88	3	3.5	....	....	50	....	204	....
N-247	3.6	....	7.1	....	25.0	**50.0**	75.1	82.9	86.3	88.2	91.2	14.7	3.5	....	**3.38**	68	3	3.0	....	....	96	....	157	....
H-8	0.0	....	3.1	....	17.4	49.0	**79.0**	82.5	84.4	87.4	88.9	11.1	3.45	....	**3.23**	....	....	3.5	3.5	....	88	....	140	....
H-12	0.0	....	0.8	....	16.0	42.5	**70.0**	80.7	83.4	90.4	94.3	7.4	3.4	....	**3.15**	....	....	2.5	....	....	79	....	240	7.4
H-31	0.0	....	2.8	....	17.9	39.0	**69.3**	78.1	83.4	89.8	91.3	12.8	3.4	....	**3.16**	....	....	4	....	....	86	....	126	3.7
H-12-582	0.0	....	2.9	8.0	20.6	45.0	**67.7**	78.5	83.1	86.1	88.5	16.7	3.4	3.15	**3.13**	....	....	2.5	....	....	65	90	....	8.9
N-205	0.7	....	1.8	....	10.0	36.0	**64.1**	73.0	78.0	81.4	87.3	15.1	3.35	....	**2.92**	91	2	3.5	....	....	80	....	181	....
N-252	1.5	....	4.3	....	16.5	41.0	**78.1**	83.1	85.3	86.7	90.1	12.7	3.3	....	**3.26**	74	3	3.5	....	....	173	....	158	....
H-16	0.0	....	0.0	....	0.6	23.5	**67.0**	92.7	98.3	98.9	99.8	1.4	3.3	....	**3.16**	....	....	2	....	....	98	176	103	1.1
H-92	....	0.1	0.4	2.9	12.9	35.8	**58.0**	74.6	83.7	89.4	93.1	11.5	3.2	3.00	**2.98**	....	....	3	....	3	74	88	....	7.2
H-8-606	0.5	....	0.8	1.8	7.1	30.0	**57.8**	76.0	85.8	91.6	94.7	10.3	3.2	2.98	**2.97**	....	....	3.5	3.5	....	88	125	....	10.3
H-40-583	0.2	....	0.6	2.3	7.1	23.0	**69.8**	85.0	90.6	93.8	95.3	9.2	3.15	3.09	**3.14**	....	....	4	....	....	127	155	....	5.4
N-248	0.4	....	1.1	....	5.5	16.0	**62.8**	80.1	86.1	89.2	92.8	6.5	3.15	....	**2.99**	75	2	2.5	....	....	112	....	126	....
H-51	0.1	....	0.7	....	5.1	25.0	**55.1**	71.6	81.8	89.7	94.4	7.2	3.15	....	**2.87**	....	....	3	....	....	80	91	....	4.9
N-204	0.5	....	0.9	....	5.1	26.5	**56.3**	77.1	85.6	89.3	93.3	8.7	3.1	....	**2.92**	78	2	2.5	....	....	81	....	120	....
N-245	1.2	....	2.6	....	9.0	21.0	**53.2**	72.4	82.7	87.3	91.6	12.1	3.05	....	**2.90**	83	2	2	....	....	44	....	169	....
N-257	0.9	....	1.6	....	11.4	31.0	**51.9**	60.3	66.1	72.3	85.9	10.6	3.05	....	**2.68**	108	2	2	....	....	44	....	150	....
N-210	1.7	....	3.1	....	26.0	49.0	**75.3**	81.6	85.3	87.3	90.9	15.8	3.45	....	**3.32**	70	3	3	....	....	169	....	173	....

For reference marks see page 390.

Table No. 5 (Continued) —*Albany Sands classified into "Rational Grades" by the Median Index method.*

	Screen Analyses*												Rittinger Indices			Grades Applied by Producers								
Screen No.	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	Clay	Median Index, from plotted curves.	Calculated, Augmented screen series. (1.41 Ratio.)	Calculated, Diminished (2 Ratio) screen series.	Grubb-Scranton Fineness Number.	C. M. Nevin's Grade Number (A. F. A. Trans., 32, 2, 182).	Producer's Grading, Shipping Memos.	Graded by Connor or Matthiessen, Whitehead Bros. Co.	Graded by George Reed, Charles Pettinos Co.	Maximum Green Permeability.	Maximum Permeability, Baked Cores.	Maximum A. F. A. Green Bond.	Maximum Green Compressive Strength Lbs. per sq. in.
Mesh Tyler	10	14	20	28	35	48	65	100	150	200	300													
Mesh A. F. A.	12	....	20	....	40	....	70	100	140	200	270	.....												
H-79	0.8	0.5	0.7	1.7	8.4	27.1	46.6	67.4	81.1	89.5	94.4	10.0	2.9	2.83	2.81	....	....	2.5	....	....	....	....	....	....
N-262	0.4	....	1.2	....	8.2	24.0	46.3	67.5	79.7	85.7	91.3	11.4	2.9	....	2.77	90	2	2.5	....	....	52	....	158	....
H-12-607	0.0	0.0	0.0	....	1.9	14.5	45.0	67.8	82.1	90.7	94.6	7.1	2.9	2.73	2.74	....	....	2.5	....	....	105	115	....	7.6
H-18	0.0	....	0.0	....	0.2	....	44.2	68.8	78.3	89.3	94.3	6.0	2.8	....	2.67	....	....	....	....	....	77	106	104	1.6
W-2.5-M	0.4	0.5	0.8	1.6	5.0	22.0	46.4	65.1	78.0	86.6	91.1	9.5	2.9	2.74	2.77	....	....	2.5	2.5	....	60	....	124	....
H-90	1.0	1.2	1.8	3.4	9.1	21.6	41.7	65.9	78.3	84.2	88.4	11.9	2.8	2.73	2.70	....	....	2	....	2	32	76	....	8.3
N-214	0.3	....	0.2	....	2.3	15.0	41.1	63.2	77.3	84.6	92.0	6.9	2.8	....	2.63	105	2	2.5	....	....	68	....	121	....
H-83	0.0	0.2	0.7	2.2	7.3	21.1	39.3	61.6	77.9	88.2	94.6	9.2	2.7	2.70	2.70	....	....	2+	2+	2.5	48	67	....	10.0
W-2.5-O	0.1	0.1	0.2	0.6	2.8	14.5	40.3	61.3	76.5	87.8	93.8	6.3	2.8	....	2.64	....	....	2.5	2.5	....	60	....	124	....
N-261	1.0	....	4.0	....	15.2	27.0	40.2	60.6	72.2	79.4	88.5	9.8	2.8	....	2.51	101	2	2	....	....	44	....	157	....
N-212	0.2	....	0.6	....	6.9	19.0	38.7	56.1	69.0	78.5	90.7	9.3	2.7	....	2.56	104	2	2	....	....	34	....	158	....
H-91	0.0	0.0	0.1	0.6	4.2	17.3	35.6	55.4	70.1	80.3	86.9	13.8	2.65	2.51	2.47	....	....	2.5	....	2.5	22	42	....	9.4
W-2-M	0.1	0.4	0.9	2.5	7.0	18.5	36.3	52.1	65.0	78.6	87.1	7.0	2.60	2.50	2.46	....	....	2	2	....	26	....	174	....
N-208	0.2	....	0.8	....	3.0	9.0	34.8	51.7	65.6	75.1	88.2	7.7	2.55	....	2.43	113	2	2	....	....	29	....	148	....
N-211	0.1	....	0.2	....	1.3	7.0	27.4	50.7	70.1	82.6	93.7	5.4	2.55	2.42	2.43	105	1.5	0	....	....	44	....	119	....
H-76	0.2	0.2	0.3	0.8	3.5	13.2	28.3	49.0	70.3	86.8	95.4	7.0	2.45	2.49	2.48	....	....	2	2	....	....	....	....	....
H-50	0.1	....	0.3	....	1.9	7.8	27.9	49.5	69.0	84.6	92.3	6.2	2.45	2.43	2.42	....	....	2	....	....	50	68	....	3.8
N-246	0.5	....	0.9	....	1.5	....	19.1	48.9	67.6	76.4	86.5	13.9	2.45	....	2.26	120	1.5	1.5	....	....	19	....	161	....
H-6	0.0	0.0	0.0	0.0	0.5	5.3	22.0	47.8	65.9	84.0	89.9	3.2	2.4	2.33	2.28	....	....	2	....	....	38	58	133	....
H-82	0.0	0.0	0.1	0.6	2.1	8.2	20.9	38.8	54.7	68.9	83.3	10.3	2.15	2.14	2.11	....	....	2—	2—	2+	26	52	....	12.0
W-2-O	0.2	0.2	0.3	0.6	1.7	5.5	20.1	36.2	54.0	72.4	84.1	4.4	2.15	2.12	2.10	....	....	2	2	....	31	....	158	....
N-213	0.5	....	1.3	....	3.8	....	16.5	33.6	51.6	67.1	84.2	12.3	2.05	....	2.06	139	1.5	1.5	....	....	26	....	159	....
H-9-S	0.6	....	1.0	....	2.2	....	12.8	25.6	51.2	78.8	90.6	5.6	2.10	....	2.08	....	....	1.5	....	....	36	39	....	4.5
H-14	0.0	....	2.0	....	7.9	....	19.5	33.5	50.8	74.0	84.3	2.1	2.05	....	2.15	....	....	2	....	....	20	43	190	6.4
N-256	0.0	....	0.2	....	2.0	....	26.9	40.6	50.1	61.7	82.2	10.9	2.00	....	2.11	140	1.5	2	....	....	21	....	208	....
H-80	0.0	0.1	0.1	0.2	0.3	0.5	1.2	12.4	47.3	80.5	93.9	5.4	1.95	1.93	1.93	....	....	1.5	....	....	39	50	....	3.9
H-78	0.0	0.0	0.1	0.2	0.3	0.7	5.0	23.2	46.9	67.0	81.5	21.9	1.9	1.88	1.84	....	....	1.5	....	....	....	....	....	....
N-260	0.0	....	0.1	....	0.6	....	2.7	14.1	44.3	66.1	84.2	10.2	1.9	1.82	1.82	154	1	1	....	....	23	....	173	....

For reference marks see page 390.

Table No. 5 (Continued)—*Albany Sands classified into "Rational Grades" by the Median Index method.*

Screen Analyses*													Rittinger Indices			Grades Applied by Producers								
Screen No.	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	Clay	Median Index, from plotted curves.	Calculated, Augmented screen series. (1.41 Ratio.)	Calculated, Diminished (2 Ratio) screen series.	Grubb-Scranton Fineness Number.	C. M. Nevin's Grade Number (A. F. A. Trans., 32, 2, 182).	Producer's Grading, Shipping Memos.	Graded by Connor or Matthiessen, Whitehead Bros. Co.	Graded by George Reed, Charles Pettinos Co.	Maximum Green Permeability.	Maximum Permeability, Baked Cores.	Maximum A. F. A. Green Bond.	Maximum Green Compressive Strength Lbs. per sq. in.
Mesh Tyler	10	14	20	28	35	48	65	100	150	200	300	.....												
Mesh A. F. A.	12	....	20	....	40	....	70	100	140	200	270	.....												
H-88	0.4	0.4	0.5	0.9	2.0	4.5	11.3	25.9	45.6	65.1	79.4	8.3	1.9	1.93	1.89	....	....	1.5	1.5	1+	26	38	....	5.0
N-239	0.0	....	0.1	....	0.3	....	5.3	25.1	47.4	62.8	81.2	14.2	1.9	1.81	1.84	153	1	1.5	....	....	19	....	159	....
W-1.5-M	0.0	0.0	0.1	0.1	0.2	0.8	5.1	18.8	42.0	62.9	75.1	12.9	1.85	1.78	1.73	....	....	1.5	1.5	....	21	....	160	....
H-81	0.0	0.2	0.2	0.3	0.4	0.6	2.1	14.4	39.9	67.4	86.0	6.5	1.8	1.81	1.79	....	....	0	....	....	26	31	....	6.5
H-9	0.0	0.0	0.1	0.2	0.6	1.8	4.6	15.7	38.7	63.4	81.9	2.4	1.8	1.79	1.76	....	....	1.5	....	....	21	....	147	3.6
N-228	0.1	....	0.3	....	0.8	....	8.0	24.8	42.7	59.3	80.3	10.0	1.8	1.85	1.82	157	1	1	....	....	19	....	140	....
N-215	0.1	....	0.2	....	0.5	....	3.2	13.2	37.1	63.1	85.6	6.5	1.75	1.78	1.77	157	1	1.5	....	....	24	....	139	....
W-1.5-O	0.0	0.0	0.1	0.1	0.2	0.5	1.8	7.4	27.5	65.7	80.9	6.1	1.7	1.67	1.61	....	....	1.5	1.5	....	24	....	140	....
N-259	0.0	....	0.1	....	0.3	....	0.8	7.8	38.5	60.9	84.0	15.3	1.65	1.72	1.74	161	....	1	....	....	18	....	145	....
H-87	0.0	0.1	0.1	0.2	0.6	1.7	4.7	15.5	34.7	56.6	74.5	6.8	1.65	1.70	1.65	....	....	1	1	0.5	17	36	....	5.3
H-11	....	....	0.0	....	0.3	....	9.9	17.6	27.5	56.6	66.0	2.8	1.66	....	1.54	....	....	1	....	....	6.4	16	180	6.4
H-5	0.0	....	0.1	....	0.1	....	5.0	21.4	34.4	52.3	62.4	6.3	1.66	....	1.52	....	....	1	....	....	13	....	163	....
H-49	0.0	0.0	0.2	....	0.6	....	15.7	23.3	31.0	51.4	72.1	8.4	1.55	....	1.70	....	....	1	....	....	16	20	....	5.3
N-202	0.2	....	0.5	....	0.6	....	1.8	7.1	27.1	51.6	81.0	9.2	1.55	1.61	1.61	....	....	00	....	....	22	....	120	....
W-1-O	0.0	....	0.2	0.3	0.4	0.7	1.2	4.1	17.5	49.3	69.1	7.8	1.48	1.38	1.38	....	....	1	1	....	14	....	142	....
N-244	0.0	....	0.1	....	0.1	....	3.1	8.1	24.6	47.6	71.8	19.3	1.45	1.46	1.50	184	0	0	....	....	13	....	175	....
N-241	0.0	....	0.0	....	0.4	....	1.6	6.1	22.5	46.2	77.3	7.9	1.45	1.47	1.52	184	0	1	....	....	22	....	142	....
N-250	0.2	....	0.4	....	0.8	....	7.0	17.6	32.1	46.4	68.7	24.0	1.40	1.55	1.59	183	1	1	....	....	10	....	200	....
H-85	0.0	0.0	0.0	0.1	0.2	0.6	1.2	4.4	17.8	42.0	69.0	6.2	1.35	1.35	1.38	....	....	1.5	1.5	1+	15	19	....	6.8
N-249	0.0	....	0.1	....	0.1	....	2.5	6.8	22.2	42.8	66.8	19.5	1.35	1.38	1.42	196	0	00	....	....	9.4	....	172	....
W-1-M	0.0	....	0.1	0.2	0.3	0.5	1.2	4.3	15.5	41.1	60.8	8.9	1.30	1.27	1.28	....	....	1	1	....	14	....	153	....
N-240	0.0	....	0.1	....	0.5	....	1.7	6.8	20.1	38.1	69.5	12.3	1.30	1.39	1.42	197	0	1	....	....	17	....	153	....
H-17	....	....	....	....	....	....	0.0	1.9	12.6	38.0	62.2	2.2	1.20	1.23	1.25	....	....	....	....	....	24	27	148	2.5
N-207	0.8	....	1.0	....	1.3	....	3.8	9.5	19.2	33.5	60.8	12.8	1.20	1.32	1.37	207	0	0	....	....	12	....	181	....
N-203	0.1	....	0.1	....	0.4	....	1.9	5.6	14.5	27.2	59.4	14.7	1.20	1.20	1.26	....	0	0	....	0	12	....	190	....
H-86	0.0	0.1	0.1	0.2	0.3	0.5	0.9	3.0	15.7	36.9	58.1	11.9	1.15	1.22	1.25	....	....	0	....	....	10.5	19.8	....	6.0
N-255	0.1	....	0.2	....	0.8	....	3.8	7.4	13.8	27.7	60.9	13.5	1.10	1.19	1.30	214	0	1	....	....	13	....	188	....

For reference marks see page 390.

Table No. 5 (Concluded)—*Albany Sands classified into "Rational Grades" by the Median Index method.*

	Screen Analyses*												Rittinger Indices			Grades Applied by Producers								
Screen No.	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	Clay	Median Index, from plotted curves.	Calculated, Augmented "screen" series. (1.41 Ratio.)	Calculated, "Diminished (2 Ratio) screen series.	Grubb-Scranton Fineness Number.	C. M. Nevin's Grade Number (A. F. A. Trans., 32, 2, 182).	Producer's Grading, Shipping Memos.	Graded by Connor or Matthiessen, Whitehead Bros. Co.	Graded by George Reed, Charles Pettinos Co.	Maximum Green Permeability.	Maximum Permeability, Baked Cores.	Maximum A. F. A. Green Bond.	Maximum Green Compressive Strength Lbs. per sq. in.
Mesh Tyler	10	14	20	28	35	48	65	100	150	200	300	....												
Mesh A. F. A.	12	....	20	....	40	....	70	100	140	200	270	....												
N-254	0.3	....	0.4	....	0.8	....	1.8	4.6	11.4	25.9	62.0	13.1	1.10	1.20	1.27	220	00	00	....	....	13	....	186	....
H-19-S	0.0	....	0.0	....	0.1	....	3.3	7.5	16.5	33.0	51.6	15.6	1.10	1.19	1.22	....	....	....	....	....	8	9.8	....	7.8
W-OM	0.0	....	0.1	0.1	0.2	0.4	0.7	2.1	10.5	28.3	48.7	15.4	0.95	1.08	1.10	....	....	0	0	....	9	....	186	....
N-253	0.3	....	0.4	....	0.7	....	1.6	3.3	10.9	22.8	49.0	27.0	0.95	1.07	1.13	235	00	00	....	....	7.2	....	200	....
N-251	0.1	....	0.1	....	0.2	....	0.9	3.0	11.3	22.4	48.1	24.1	0.95	1.05	1.11	233	00	0	....	....	7.2	....	188	....
H-84	0.0	0.1	0.1	0.3	0.4	0.7	1.2	3.0	10.4	26.1	47.3	9.9	0.90	1.06	1.10	....	....	1	1	00	9.2	10.9	....	9.4
N-258	0.1	....	0.2	....	0.7	....	4.8	10.2	16.0	27.0	44.4	16.7	0.85	1.14	1.16	233	0	00	....	....	7.7	....	190	....
N-221	0.5	....	0.7	....	1.0	....	3.2	6.8	12.6	21.4	44.4	20.1	0.80	1.08	1.12	231	00	00	....	....	7.5	....	186	....
N-209	0.2	....	0.3	....	0.6	....	2.0	3.7	6.5	12.7	40.1	21.1	0.80	0.96	1.00	235	00	00	....	....	10.7	....	203	....
N-206	0.1	....	0.2	....	0.7	....	5.4	9.4	14.1	19.9	41.1	18.9	0.75	1.08	1.12	232	0	1	....	....	9.7	....	199	....
H-19	0.0	....	0.0	....	0.4	....	1.4	2.3	5.0	19.9	33.7	22.5	0.60	0.90	0.91	....	....	....	....	....	8.5	....	255	7.5
H-7	0.0	....	0.6	....	0.9	....	3.5	7.8	13.9	17.2	22.7	10.9	0.40	0.90	0.92	....	....	1	....	....	9.5	....	210	6.7
H-74	0.0	0.0	0.0	0.1	0.2	0.5	0.8	1.1	1.8	5.8	18.5	22.2	0.20	0.74	0.71	....	....	0	0	....	3.7	....	....	7.6

*Cumulative Percentages caught on Screen Indicated Clay free sand (AFA washing practise) = 100 per Cent. Clay is reported in per Cent of dry sand as received.

**Lab. No. Prefix N—Analyses by Nevin (AFA Trans. 32, part 2, 1925).

†Lab. No. Prefix H—Analyses by Hansen.

††Lab. No. Prefix W—Standard Albany Sand Grades of Whitehead Brothers Company—analyses privately communicated by H. B. Hanley.

00 and 3½ (4 and 5 are occasionally used) are thus of value rather as selling points than as true description of fineness of Albany sands.

The essentially linear character of the relation between "Grade" and average "Rittinger Index" suggests the propriety of selecting a definitely linear relation as a basis for establishing fineness limits to the various grades. The most simple relation of that nature is indicated by the diagonal line in Fig. 4 and the relation is further expanded in Fig. 5.

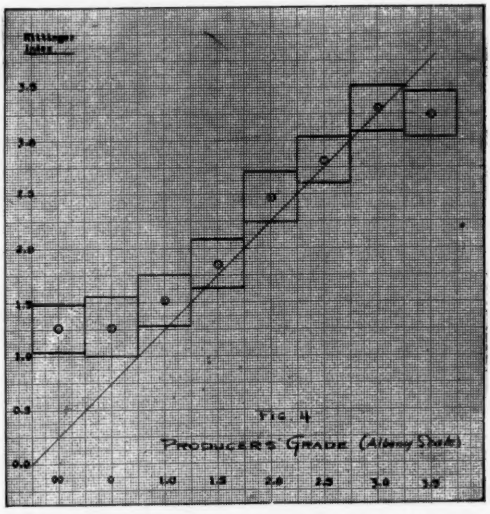

FIG. 4—THE RELATION BETWEEN RITTINGER FINENESS INDICES AND GRADE NUMBERS AS ASSIGNED BY ALBANY DISTRICT SAND PRODUCERS—DATA GIVEN IN TABLE 5

The writer proposes that molding sands and core sands be classified into fineness grades according to "Rittinger Fineness Indices" as shown in Fig. 5, the same relations to be extended indefinitely to cover the coarsest sands used anywhere in the foundry.

On the whole, the proposed grades differ but slightly from the present Albany sand grades. Of the Albany sands covered

by the writer's records (some 350 sands), the figure in each square in Fig. 5 indicates the percentage so graded by the producers as to fall within the proposed grade classification.

Some thirty-five of the sands in Table 5 are of special interest. A large proportion of sand produced in the Albany district is mined, graded and shipped under the supervision of Mr. Matthiessen or Mr. Connor, representing a large producer, or by Mr. Reed who represents another large producer. These three

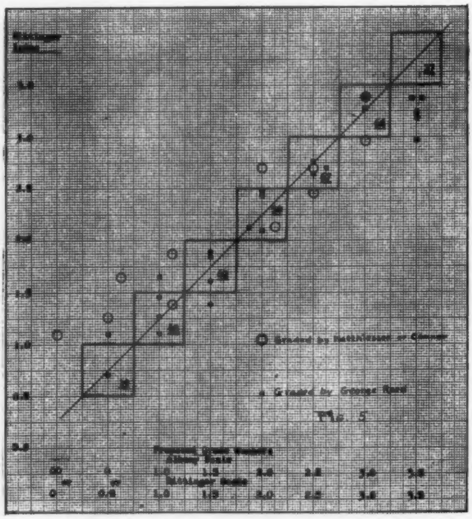

FIG. 5—THE RELATION BETWEEN RITTINGER FINENESS INDICES AND GRADE NUMBERS ASSIGNED BY ESPECIALLY SKILFUL COMMERCIAL SAND GRADERS IN THE ALBANY DISTRICT

gentlemen are generally acknowledged (throughout the Albany district) to be exceptionally expert graders of Albany sands. They very kindly graded a number of sands with results which are superimposed upon the grading diagram in Fig. 5. Possibly a little of the personal element in touch grading is evident in these results, the Connor-Matthiessen grading scale agreeing a trifle more closely with the proposed scale than that of Mr. Reed.

Rittinger Index Versus Physical Properties of Sands

The permeability of sands is undoubtedly related directly to the fineness of sands although there are secondary variables that make the relation far from exact. In Fig. 6 are plotted the maximum green permeabilities for the Albany sands listed[10] in Table 5.

The average of the permeabilities of the sands within each proposed grade group fall very nearly upon the line CC, according to which:

$$P = 3.10 \times D^{1.5} = \text{(approximately) } 3.10 \times 2^{N+1.5}$$

where P is the permeability, D the grain diameter in mils, and N is the Rittinger index. Half of the sands in each grade group developed permeabilities lying within the area enclosed by the lines BB and CC, the corresponding "constants" being 2.50 and 3.70 instead of the mean value 3.10. According to probability function studies, less than 2 per cent of all Albany sands may be expected to show permeabilities above those indicated by the line EE (constant 5.00) and less than 10 per cent may be expected to show permeabilities lower than indicated by the line AA (constant 1.86).

The permeabilities of dry sand cores (molded for maximum green permeability and baked at 350 degrees Fahr.) are shown in Fig. 7, the line CC of Fig. 6 being superimposed for reference.

Similar studies of New Jersey sands (Amboy district, Lumberton district, Millville district) yielded very similar results; except for such artificial products as "Ottawa Flint Shot" of extraordinary grain size uniformity (see Table 4) it seems very doubtful that natural sands will develop permeabilities higher than $5 \times D^{1.5}$.

It is possible to show by analyses selected from Table 5 that with two sands of the same Rittinger index (average fineness) the more uniform sand will be the more permeable, but it is rather more striking to show this in another way.

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[10] Here, again, the inclusion of 214 additional Albany sands in no way alters the conclusions drawn.

In Fig. 8 are shown the relations between permeability (green and dry) and Rittinger index for systematic mixtures of two pairs of natural sharp core sands bonded with ½ per cent gelatinized starch in order to avoid the complications introduced by clay bonds. The permeability of any mixture of two sands is less than the weighted mean permeability of the two constituents of the mixture; the mean permeability may be correctly shown by joining the points AA′, BB′, CC′, DD′. In particular,

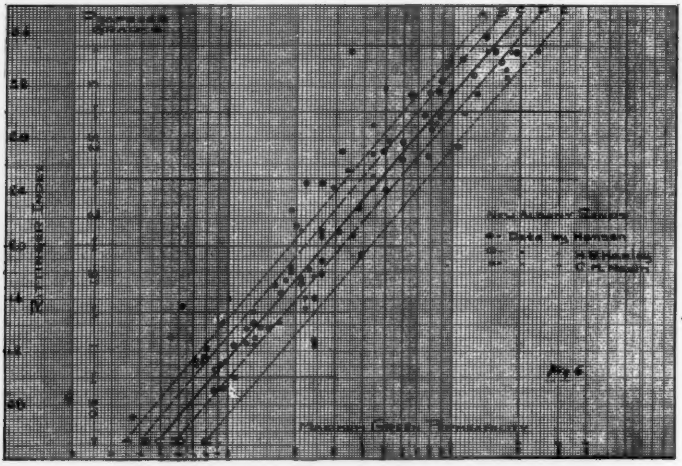

FIG. 6—THE RELATION BETWEEN RITTINGER INDEX, PROPOSED GRADE NUMBER, AND MAXIMUM GREEN PERMEABILITY OF SOME 300 COMMERCIALLY PRODUCED ALBANY MOLDING SANDS—THE CURVE CC INDICATES THE MEAN AVERAGE OF MAXIMUM GREEN PERMEABILITIES FOR ALL ALBANY MOLDING SANDS TESTED

the first addition of a coarse sand to a fine sand generally leads to a decrease in permeability rather than the reverse. The density of a mixture of two sands is generally higher than the density of either constituent.

Sands with nearly spherical grain (Ottawa sands for example) are generally less permeable than sharply angular grain sands of the same screen analysis. The spherical grains appar-

ently slip over one another more readily than the sharply angular grains; at any rate they resist packing less than the sharp grains; densities of 1.60 versus 1.43 (grams per cubic centimeter, moisture free basis) have been observed for pure silica sand pairs of this nature.

The addition of clay (up to 20 per cent) to sharp core sands very frequently leads to increased permeabilities, but this is largely due to the method of determination, for with heavily rammed sands the addition of clay invariably decreases the per-

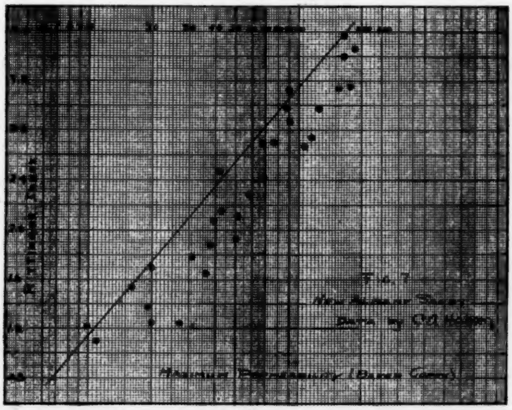

FIG. 7—THE RELATION BETWEEN RITTINGER INDEX AND THE MAXIMUM PERMEABILITY OF DRY ALBANY SAND CORES (CORES MOLDED MOIST AND BAKED)—THE SOLID CURVE SHOWS THE MEAN VALUE OF GREEN PERMEABILITY AND IS INTENDED MERELY AS A REFERENCE CURVE

meability. Clay, however, has less direct bearing upon permeability than fineness of grain, uniformity of grain, shape of grain, or the fine silt that we include under "clay substance," and a very fat clay affects the permeability less than a relatively nonplastic clay.

There is no observable regularity in the relation between fineness and strength (green or dry) of Albany sands, nor is there any observable regularity in the relation between "clay substance" and strength (green or dry). The writer believes

that much of this lack of relation is due to the inclusive nature of the "clay substance."

Albany sands are of relative recent geologic origin. The originally deposited sands were mixtures of silica grains and rather easily friable slatey shale grains. What effective bond the Albany sands possess is due to the decomposition of the slatey shales, principally by soil acids. It is common knowledge in the Albany district that the best molding sands are to be found in "wood lots"—i. e., underlying surfaces that are, or were, heavily timbered. The timber presupposes a relatively sta-

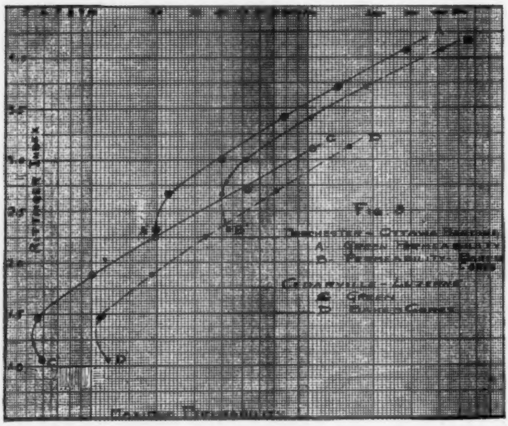

FIG. 8—RELATION BETWEEN PERMEABILITY (GREEN AND DRY) AND RITTENGER INDEX FOR SYSTEMATIC MIXTURES OF TWO PAIRS OF NATURAL SHARP CORE SANDS

ble surface, soil of long standing, and prolonged action of the products of decaying vegetation carried down into the sands by percolating waters—the shales are more or less thoroughly converted into effective bond clay. Much of the Albany sand is very close to the surface, subject to shifting by wind and water, and in such sands the shale has either not been appreciably converted to bond clay or the clay has been washed out. All the intermediate shades between good sands and poor sands are to be found in shipments from irresponsible or unskilled producers.

The writer has frequently found "wood lot" Albany sands with 4 per cent "clay substance" that were far more effectively bonded than others of the same grain size containing 12 or 14 per cent "clay substance." Furthermore, none of the tests so far proposed for the determination of the green strength of sands (tensile, compressive, cross bending or the A. F. A. cohesiveness tests) is sufficiently direct in the determination of that effective bond which is essential in a molding sand. Too large a fraction of the strength determined by these tests is due purely to the surface tension of the water in the test sample. In this respect the study of water bonded sharp sands is of particular interest in showing the elusiveness of "green bond" strength. Generally, for water bonded sharp sands, the "green strength" varies inversely with grain size; the less uniform the sand, the higher the "green strength"; the more nearly spherical the grain, the higher the "green strength"; it is very readily possible to find water bonded sharp sands sufficiently "strong" to permit easy molding—but castings cannot be made in them.

It is certainly true that a skilled sand producer in the Albany district can more correctly judge the "strength" of a sand by wadding the sand into a ball, breaking the ball, and observing the fracture than can the writer on the basis of laboratory determinations of "clay substance" and "green strength."

In spite of very considerable effort to formulate some practical strength index, based upon accepted sand testing methods, whereby the fineness index to grade might be properly qualified, the writer confesses that he prefers to rely upon the skilled producer's old familiar hand test with its classification of "strong," "medium" and "weak." The determination of strength of baked cores is an effective measure of the bond value of molding sands—but it is rather impracticable to introduce this into specifications governing the purchase of sands.

Generally, permeability and strength are antagonistic; a strong Albany sand is seldom above average in permeability, a weak Albany sand is seldom below average in permeability, although the permeability of either class may be ruined by injudicious admixture of top silt or fine sand.

In some other districts, notably Millville, N. J., the "clay

substance" is either all effective bond (though not a particularly excellent one) or it carries a more or less constant proportion of effective bond; at any rate the determination of "clay substance" is a fairly effective measure of the effective bond strength.

Conclusion

It is probably too early to attempt to draw definite conclusions in regard to the requirements of molding sands for specific foundry purposes, but it seems to the writer that even tentative conclusions, if they are based upon careful attempts of correlate laboratory tests with foundry observation, are better than no conclusions.

The general requirements of sands are somewhat as follows:

1. Sands must be sufficiently mobile so that they may be made to conform to the shape of the pattern or core box with a practicable amount of ramming.
2. The sands must develop sufficient strength, when moderately rammed, so that they will retain the shape of the pattern when the pattern is removed.
3. The sands must be sufficiently permeable, when moderately rammed, to permit the escape of gases generated at the pattern surfaces when molten metal is poured into the molds.
4. The sands must retain sufficient strength when dried, either in the oven or by the heat of the incoming metal, so that the mold will not cut or wash.
5. The sands must be sufficiently fine in grain size to yield smooth mold surfaces if the resulting castings are required to be smooth and clean as to surface.
6. The sands must be sufficiently refractory so that they will not melt, or sinter badly, when exposed to molten metal temperatures as in ordinary foundry practice.

So far as this paper is concerned, only the third and fifth of the above requirements need be considered, for these are the requirements most intimately affected by differences in fineness of grain. It is obvious that these requirements are essentially opposed

to one another, and that common sense must rule in compromising between them.

For light gray iron castings, not exceeding ¼ inch in section, sands with a permeability of 15 as determined under laboratory standard test conditions, have yielded consistently sound castings, while sands with a permeability of 10 have led to more or less consistent trouble with unsound castings. By careful selection, No. 1 sands (proposed grading scale) can be found to meet the above requirements, and the general run of No. 1½ sands will meet them. The difference in casting surface, as between No. 1 and No. 1½ sands, is not readily evident.

For gray iron castings up to an inch in section a minimum permeability of 40 is essential for the production of consistently sound castings when the molds are made from heap sands hand rammed, or jolted, or jolted and squeezed as in usual foundry practice. The "Sand Slinger" normally produces a considerably more compact mold than any of the other ramming practices with which the writer is familiar and it requires rather more open sands—perhaps 60 permeability for the same type of work. The 40 permeability requirement can be met with carefully selected No. 2 sands or with the general run of No. 2½ sands. The latter approaches the limit in grain size at which suitable casting surfaces may be maintained without resort to special facings.

For the heaviest of green sand iron castings, prepared with sea coal facings backed with weak heap sands, consistently acceptable results have been obtained with carefully selected No. 2½ sands, and with the general run of No. 3 sands. The molds require "leading," i. e. well brushed in graphite at the pattern surfaces, to insure commercially acceptable casting surfaces.

The heaviest gray iron castings that can be shipped have been made with very consistently good results in pitch bonded Millville gravels grading No. 4 (about as fine grain size as can be found in this type of sand). Both molds and cores are made from the same sand, and both, of course, are dried or baked, and the pattern surfaces are washed with clay-graphite facings. The green permeability of these mixtures averages 80 and the permeability of the baked cores about 150.

The general run of brass foundry castings, including brass,

bronze, copper, and white alloys, are being made consistently sound in No. 1½ sands with a permeability of 20. Sands with a permeability of 10 have given more or less consistent trouble in making sound collector rings, the slightest imperfection in the machined brush surface being cause for rejection. Except in respect to "art plaques" and castings of that general type, there seems very little advantage in surface to be gained by using sands materially finer than No. 1½ in fineness grade, and when the finer sands are warranted at all, they should preferably be used as thin facings backed up with the more open sands.

Practically all types of steel castings have been made with excellent results in both green and dry sand mixtures based upon Ottawa run of mine sands which normally grade No. 3½, and in Dorchester sands (see Table 3) of No. 3 to 3½ grade. Cores made from No. 2½ grade sands have given little or no trouble, and it seems certain that molding sands of this fineness are ample for the heaviest sections.

In general, since the choice of sands, in respect to fineness, is determined on the one hand by permeability requirements, and on the other by casting surface requirements, better results may be obtained by the proper selection of simple sands than by using admixtures of coarse and fine sands. If sufficient coarse sand is used in the mixture to insure permeability, it will also be the coarse constituent of the mixture that determines the surface character of the mold—and the surface character of the mold quite definitely determines the surface character of the casting.

An extreme range of fineness in grade of sand is certainly not required to accommodate the widest range of foundry work, nor is the surface of the casting affected appreciably by a moderate change in fineness of the sand used in its preparation. The writer sincerely believes that it is possible to do away with complex sand mixing formulæ that are still far too common in many foundries.

Appendix

Since the above paper was written, the writer has happened upon two articles in the A. I. M. E. Transactions (Vol. LVII, pp. 472-480 and pp. 481-485) bearing directly upon the subject matter.

The first of these reports the conclusions reached relative to screen standards in a conference between the Bureau of Standards and the representatives of various technical and scientific societies, including the American Foundrymen's Association. The writer's criticism of the A. F. A. screen series seems to have been anticipated: "Some industries may have occasion to use all of the sieves in a certain section of the series (the Richards series) and none of the others, while in other industries it may be desirable to use only certain sieves selected from the whole range of the series. In making such selections it is recommended that this be done on some systematic plan as, for example, the selection of every other sieve, or of every fourth sieve in the series——." The writer has been unable to find any later reference in which the above recommendation was withdrawn.

In the second article, John Randall suggests the use of the logarithms of the mesh openings, taking 0.001 inches as the zero starting point. Mr. Randall used the conventional logarithms (base 10); the writer uses Rittinger scale units which are equivalent to the logarithms (base 2) of the corresponding mesh openings.

Discussion

M. D. Pugh: I would just like to ask Mr. Hansen if he doesn't feel that sometime, due to the nature of supply of sand, it may have to be blended according to grain size.

C. A. Hansen: Whether or not sands shall be blended according to grain size, or for the control of any other physical characteristic is largely a matter of economics. I prefer simple natural sands when such are suitable and reasonably cheaply available. I would not insist on this preference to the extent of using Albany sands in Portland, Oregon, for example; I am reasonably certain that some sort of suitable molding sand could be blended from materials closer at hand.

Portland may not be exactly the proper example, for Albany sands do go down the Hudson River and through the Panama canal to Portland at a freight rate approximating five dollars a ton and I know of Western foundries that regularly use Albany sands under a freight handicap of fourteen dollars a ton.

A. M. Clark: Mr. Hansen has just mentioned about the condition in Portland. You might be interested to know that in the steel foundries the major portion of our sand is brought from Belgium. It is economical for

us to bring sand from Belgium rather than to bring it from this country, due to the freight rates. We have plants all up and down the coast, Los Angeles, San Francisco, and Portland.

C. A. Hansen: Mr. Clark's use of Belgian sands is a pertinent example in sand economics. The Pacific Coast has used large quantities of Chinese pig iron and large quantities of Belgian coke in making cupola mixtures. There is a good deal of ballast transport to our Pacific Coast, and I know that sand and coke have been freighted over from Belgium at about $1.75 a ton. There are excellent sharp silica sands in Southern California, and there are no doubt perfectly good bonding clays along the West Coast somewhere, so that suitable molding sands can no doubt be blended from materials that do not require a transcontinental haul, but it is doubtful if these raw materials could be assembled in Portland at a $1.75 freight haul. Albany sands can scarcely be hauled across New York State for $1.75 a ton.

Chairman R. A. Bull: I know a steel foundryman in Los Angeles using Ottawa sand from Illinois, and my recollection of his statement to me some time ago—and he would be perfectly willing to make it here, I know, if he were present—is that the freight was something like $14 or $15 a ton.

A. M. Clark: The rate on sand to all Pacific Coast points from the Ottawa district is $10 a ton, if the sand is bought from Portland or Seattle, and is laid down at our plant from Belgium at about five dollars a ton. In San Francisco it is bought for about $3.50, they bring it over there largely for the manufacture of glass, and, incidentally, for the foundry.

M. D. Pugh: One more thing in this question of testing sands. Mr. Hansen in Table 1, as you will note, refers to the Tyler series, the United States series and the Rittinger formula. The question was asked us over at our booth the other day on two or three different occasions, "Why have two different series?"

Briefly, it is this. The U. S. Bureau, when it adopted standard sieves, did so with little regard to the manufacture of wire cloth in commercial quantities. That is, whether it would present problems from the standpoint of a weaver. The Tyler series was based upon commercial grades of wire which we use every day and which we produce all the time, and it can be furnished in commercial quantities as well as the testing sieves. That is the reason for the variation. However, if you will note the ratio of the openings, there is very little difference between the U. S. series and the Tyler series.

C. A. Hansen: For several years I was concerned with mining matters and the mining industry, I believe, uses testing screens to a greater extent than any other industry. I do not remember ever having seen other than Tyler standard screens in use in any of the mine laboratories I visited.

I assume, therefore, that the Tyler series of screens is at least as well known as the U. S. series. The two series of screens have the same mesh openings within the accepted tolerances, but the two series of screens are not characterized by the same screen numbers. Nominally the numbers used to identify the various screens refer to the mesh count; a No. 40 screen is supposed to have 40 meshes to the linear inch; but the number is somewhat arbitrary for the U. S. No. 40 screen specification calls for 38.02 meshes to the inch. The equivalent Tyler screen is known as No. 35 and it may or may not have exactly 35 meshes per linear inch.

Now the important point in a testing sieve is the size of the mesh opening rather than the number of mesh openings, for the size of the opening determines the grading of the sands tested. The fact that the two most largely used sieve series have the same mesh openings but are not identified by the same numbers leads to confusion, and I was very much interested in trying to avoid this unnecessary confusion. Both series of screens are based upon the same fundamental proposal of Rittinger, namely that the mesh opening of each screen in the series should be twice that of the next finer screen. This suggested a simple way of renumbering the screens which would avoid confusion and which would also be less arbitrary than the present numbering system. This whole matter has been discussed in detail in the body of my paper and there is no need to repeat the discussion. My paper on grading may be considered a minority report of the subcommittee on the grading of sands.

M. D. Pugh: I just want to say this again with regard to the relation of those two series. If you will take the reading glass and count the Tyler meshes, you will find they count exactly according to our numbers. However, as you know, the size of the openings is determined by the size of the wire used. Therefore, if you take the U. S. Bureau series, you will find that the wires vary in diameter from the same number or equivalent opening of the Tyler series. Therefore, due to the fact that the Bureau of Standards use a different size of wire, their meshes count differently to get the same opening as the Tyler series.

Strength Tests of Foundry Sands

By T. C. Adams,* Ithaca, N. Y.

The larger foundry organizations in seeking to lower the cost of production of castings and prevention of waste have as a part of their progress of economy turned to a more careful control of the sand heaps in use upon the foundry floor. It is found profitable to conduct systematic research regarding the required properties of foundry sands and make frequent tests of the sand in use on the foundry floor so that the condition of this may be continuously controlled to the best interests of the foundry.

Sands for foundry use must possess properties which distinguish them from common sands. They must be permeable enough to permit the easy passage of gases through them and must be sufficiently coherent so they will retain the form given to them by molding operations, under shocks and stresses to which the finished mold is unavoidably subjected in handling and while the molten metal is being poured into it. Also sands must be refractory enough that they will not fuse at the temperatures of the molten metal and must have a texture which will produce the required surface upon the finished casting.

When the foundryman selects a sand to be used for some specific purpose he must consider whether the sand possesses to a sufficiently high degree each one of the properties noted and when the sand is placed in use he must assure himself that the sand retains the properties desired. Means of testing sands furnishes him with a method of measuring and expressing numerically strength, permeability, resistance to temperature, and the size of the grain and minimizes the necessity of relying on judgment with its confusing vagaries.

In this paper the testing of only the strength properties possessed by foundry sands is discussed. In the forepart of the paper the relation between tests and foundry practice and the general problems involved in carrying out the tests and applying

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them to foundry conditions are treated. The second part of the paper describes apparatus used to make strength tests and prepare test specimens. It also gives instructions and comments regarding their use and the purpose to which they are best adapted.

Part I

GENERAL PROBLEMS IN STRENGTH TESTS OF FOUNDRY SANDS

A—Nature of Foundry Sands and the Relation of Their Constituents to Their Strength

The term "foundry sand" will be used in this paper as a name for any sand used to make molds or cores in which or around which molten metal is cast. This includes all sands used in the foundry except such as sand blast sands and parting sands. Foundry sands may be divided for the purpose of this paper into two groups; those sands whose binding properties are due to constituents naturally found in the sand (naturally bonded sands) and those whose strength or bonding power is due to constituents added to the sand at the time it is prepared for use in the foundry. The first division has but one important member, molding sand, but the division is the first in importance because of the quantity of molding sand used and the number of varieties in use. The principal divisions of the second group are core sands, sands bonded to make dry sand molds, and steel sands. Core sands must often owe their strength to admixtures of oil and subsequent baking, though very rarely a natural bonded sand may be used for cores. Steel sands are usually bonded by mixing them with a refractory clay.

Molding sand comprises grains of sand mixed with finely divided material, usually clay, which gives coherence to the coarser particles. The percentage of clay varies from 5 to 40 per cent. It is present in small enough amounts so that it does not destroy the readily permeable nature of the sand, yet it is present in sufficiently large amounts to give comparative rigidity to a mass of sand which has been moistened and compacted. It

is possible to duplicate natural molding sands with a fair degree of success by mulling together clay and sharp sand. This is not economical in most cases nor gives a molding sand with desirable properties as those which can be found as part of natural geological formations in a number of localities over the world.

The bond material in molding sand is colloidal material, which is to say, it is so finely divided that it takes on physical properties much different from ordinary solids, the important one in the case of molding sand being coherence or adhesion. Though the behavior of colloidal materials has been extensively studied, the exact fundamental reasons for their properties are not known. The common colloidal materials of molding sands are alumina, silica, and iron compounds. Clay may contain amounts of all three, though it is principally colloidal alumina.

The cohesion of molding sand is dependent upon: first, the amount of bonding material; second, the kind of bonding material; third, the texture of the sand; fourth, the relations existing between the sand grains and the bond material. It is clear that colloidal alumina may not have the same bonding power as an equivalent amount of colloidal silica or iron, so the first statement is justified. Which colloidal material is the more effective bonding agent has not been shown. It is also probable that as more of the colloidal material is added to the sand mass, within certain limits (as the addition of colloidal material is carried to an extreme the sand ceases to be molding sand) the strength of the sand will increase. Nothing definite has been determined as far as the author is aware regarding the relation between amount of colloidal material and strength of the sand, though it is recognized that there is a general relationship. It would be valuable to know whether the strength increases directly with the amount of binding material (colloidal material) or in some other relation. While considering the results of research which has been done in this field it should be remembered that clay as determined by most tests is not all colloidal matter.

The colloidal matter must cause cohesion of the sand by coating the grains and acting as a coherent between them. The distribution of the coating material on the sand grains will depend

upon the texture or grading of the sand, that is to say, upon the average grain size of the sand and the relative size of different sand grains. This must then enter as the third factor in strength. Finally, it seems to be true that two sands may have the same clay content (colloidal material), thus having the same amount and kind of bonding material, and may have the same texture, yet not have the same inherent strength. It is thus necessary to introduce a somewhat indefinite factor called here "relation between bonding material and sand," to fully explain the variation of strength between different sands. What the nature of this factor is or perhaps its non-existence rests with further research on molding sand to show.

The fundamental stresses to which sand may be subjected are tension, compression, and shear. Another stress variously called cross breaking, bending, or transverse stressing, is recognized and is a combination of the other three. The stressing of sand specimens by each of the four stresses until they break and the measurement of the stresses required to break the sand specimens gives the four strength tests employed in foundry sand testing: tensile, compressive, shear, and transverse tests. The shearing test is of little importance.

To make a tensile test of a sand specimen it must be pulled until it breaks apart; to make a compressive test of a sand specimen this must be compressed until it collapses; to make a transverse test a sand specimen in the form of a bar must be bent until it separates in two pieces. To make each of these operations a test, some apparatus must be employed which is able to measure the stresses at the point of failure in each case.

Sand is much weaker in tension than compression. When a transverse test is made and the tensile strength at which the specimen broke is computed, this does not agree with the tensile strength obtained by a direct test. The reason is partly due to the influence of shear and partly due to the inexactness of the methods known of calculating the tensile stress.

Sands, then, may be subjected to compression, tension, shear, or a complex combination of these stresses as in bending. In the foundry, sand is expected to stand over the tops of cavities inside the mold. There is an opportunity here for the top of one

of these spans of sand to break in either tension, compression, or bending. If the roof is long and flat and unsupported from above it will bend. If arched up, the sand will be in compression. Spalling may take place from the roof, in which case, the failure is a tensile one.

A sand mold is severely treated at the time the molten metal is poured into it. Abrasion of the sand, commonly called washing, will take place in the gates of the mold and at sharp corners if the sand is weak. When the compressive strength of the sand is high it will be better able to withstand the direct impact of the molten metal which drops on it though the tearing away of particles of sand is failure in tension. Where heavy cores are set on chaplets the sand above and below the chaplets is severely stressed in compression. In the handling of molds and cores they are unavoidably subject to knocks and jars which make necessary a strongly cohering sand.

At present no definite information can be stated regarding the strength requirements of sands which are to be used for specific purposes. This is due in the first place to the lack of a standard testing code which has been in existence long enough to permit investigators to make known the results of their investigations. Secondly, the study of sands has not been undertaken extensively. Under the encouragement of the American Foundrymen's Association both of these difficulties are being quickly dispelled.

Notwithstanding the lack of definite information regarding the strength requirements of sand which is to be used for a specific purpose it is possible to point out uses where high and low strength are necessary with the benefit that some start will be made toward a proper and valuable application of testing practice. Small green sand molds which are not handled and are fairly compact may be made from sand of low bonding power. With larger molds the abrasion by molten metal and the strains they are subject to become greater. Loams for pit molding must have special properties. Of great interest from a testing standpoint are those sands concocted for use in steel casting. Here the strength required must be medium or better and this strength

must be made to exist through the addition of fire clay and subsequent mulling in a sand naturally having little or no strength. Small oil bound cores must be strong to withstand handling. Thin, intricate, or slender ones must be made from especially strong sand and binder mixture. Such cores are the most easily broken by handling and by the metal as it is poured into the mold. Sand used for green sand cores must have unusually high strength. Dry sand molds are moved to the drying ovens. This will strain them and require that they be made of sand which coheres well when damp.

B—How Strength Tests Are Employed

Tests may on one hand be made for purely research and study purposes or on the other hand for routine control purposes of the foundry. For research more elaborate tests are conducted which require on the part of the one planning and performing the tests, skill and patience, as well as broad training and initiative. This class of testing work belongs to the research department, if one exists, and should be under the control of the general management of the foundry. Research tests are made to establish the practice of the foundry, correct old, wrong ways of doing and introduce new, better ways. The acceptability of new brands or kinds of sand which it is contemplated using in the foundry should be approved by the research department.

Control tests made to keep the sand used in the foundry up to standard must be simple, must be of such nature that they can be quickly carried out, and must be easily understandable. Unskilled workmen often make these tests. Simple, quick operating apparatus is required for the number of tests which must be performed in a short time is great. This branch of testing belongs in the foundry, close to the work, under the immediate control of the foundry superintendent. Molders and foundry workmen should be taught to understand and apply the result of these tests. The testing of new shipments of sand will be done in the control department.

Small foundries having no scientific staff will find foundry control tests most suitable for their needs. They may do what

research testing they desire in the foundry with the same apparatus used for the control tests.

The four strength tests which have been proposed for testing foundry sands are tension, compression, shear, and transverse tests. There does not seem to be any advantage offered by any one of these except as it may occur in the carrying out of the test and its technique. Sands which show relatively high strength with one test show relatively high strength with another, though an individual sand may have a markedly different resistance in tension, compression or shear. It will be assumed for the time being that any test used will give the relative strength of different sands. So far as is known, this is the case, and it will permit a discussion of various strength studies which may be undertaken, without leading to the confusion a simultaneous discussion of testing technique would bring.

Of most importance in testing green foundry sands is to determine the relation between strength and moisture content. With some sands a great change in strength follows a small change in moisture content. With all sands some change takes place so that if strength must be kept high it is necessary to find the water content which develops the best strength. Some have contended that their greatest success was obtained when the sand was used in the foundry at a higher water content than that at which the highest strength was obtained in the test, but this may have been done to humor the molders.

In addition to containing sand grains and colloidal material molding sand nearly always contains some silt. Silt may be described as very fine sand, or as clay which is too coarse to be colloidal. There are no data available regarding the effects of silt upon strength of molding sand, but it is said by some foundrymen to reduce the strength. This view requires confirmation by systematic research tests.

According to its test code the American Foundrymen's Association considers as silt any particles that will pass through a 270 mesh U. S. Bureau of Standard sieve and will settle within 5 minutes at the bottom of a jar of water in which it has been well stirred. The part which remains in suspension in water after 5

minutes' settling is considered to be clay and all particles retained on a 270 mesh sieve are considered to be sand.[1]

The American Foundrymen's Association also gives a test for colloidal material which depends in its action upon the absorption of dye by colloids. Full details of this test are given in the publication referred to.

The difficulty of both of these tests is that with the settling test the differentiation of silt and colloidal clay is to some extent arbitrary and with the dye absorption test other constituents of the sand absorb some of the dye and results given by the test are somewhat erroneous. In a measure, however, these tests are valuable in giving the colloidal content of the sand which bears a rough relation to the strength of the sand.

A test has been devised by Eugene Smith of the Crane Company, Chicago, Illinois, which separates a sample of sand into fractions depending upon the size of the particles by placing a sample of the sand in a vial partially filled with water and vibrating the vial for a period of time. This indicates the proportion of clay, silt and sand grains contained in the sand and is valuable in a rough way to indicate the strength as well as other properties of the sand.

In this paper up to this point, by strength of molding sand has been meant the strength which potentially lies in the sand, but which requires the addition of moisture and compaction to develop. From this point on the term potential strength will be used in its proper meaning and the term strength will mean the true strength developed by the sand.

The true strength of molding sand, provided the moisture content is the same, always increases with the compaction. The relation, however, is not a direct one.

The strength of many molding sands for a given compaction increases with the addition of water until a maximum strength is developed then decreases with the addition of more water. Other sands are strongest when they have just enough water to keep them from crumbling, while still others are strongest with a water content so high that a slight further addition of

[1] Resume of Activities of the Joint Committee on Molding Sand Research, published June 1, 1914, by the American Foundrymen's Association.

water will cause them to melt into mud. The point of maximum strength may thus lie below, within, or above the moisture content range that sands are used in the foundry.[2]

Table 1* gives the mechanical analysis, dye absorption figure, permeability, and strength at various water contents for various typical molding sands.

When naturally bonded molding sands are baked to make dry sand molds the bonding material does not act the same as that in green sand molds. The baking temperature used is high enough to destroy the colloidal properties of the binding material and the sand grains are then held together by baked clay which has the same cohesive properties as the clay of a sun-dried brick. Oftentimes additional binding material is added to sands which are to be used to make dried molds and they no longer belong to the class of naturally bonded sands.

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*Explanation of Table 1:

SAND No. 1

This is a core sand of remarkably uniform grade and freedom from fine material. It would be considered to be of uniform grade. The permeability is medium to high. The permeability of core sands is determined when they are dry. Core sands of the nature of this one have no appreciable strength before they are mixed with some such material as core oil and baked.

SAND No. 4

This is an unusually fine molding sand. It contains an inordinate amount of clay material and for this reason the adsorption of dye is very high. The permeability is very low but the strength is reasonably high. It is notable that the strength does not change greatly with a considerable range of moisture content.

SAND No. 715

This is a rather medium to fine grade core sand, the separate particles are well graded and the permeability is moderate to perhaps low for a core sand. Strength and dye adsorption were not measured.

SAND No. 529

This is a rather coarse steel sand. Before use it must be mulled with fire clay. It has no strength before this is done.

SAND No. 531

This is a very coarse molding sand or molding gravel. The strength and dye adsorption are moderate. The permeability is high.

SAND No. 211

This is an Albany sand of grade 0. It is a medium to fine sand. The strength, permeability, and dye adsorption are moderate. There is a very small change of permeability and strength for a comparatively large change in moisture content. The sand particles are well distributed on the various sieves.

SAND No. 210

This is an Albany sand of grade 3. It is a medium coarse molding sand. There is a considerable change of strength and permeability for the range of water content through which the sand was tested.

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[2] The relation of water to the bonding strength and permeability of molding sands, C. M. Nevin, Trans. American Foundrymen's Association, Vol. 32, Pt. 2, Page 168.

Table 1

PROPERTIES OF TYPICAL FOUNDRY SANDS

Laboratory Number	Locality From Which Sample Was Obtained	Use to Which Sand Is Put	Sieve Test — Percent retained on various sieves.										Clay Content Percent	Sum of Percentages	Dye Adsorption Figure	Water Content at Which Test Was Made	Percent Bond Strength A. F. A. Test	Permeability.
			6	12	20	40	70	100	140	200	270	Pan						
1	Pacific Grove, Cal............	Core	0	0	0	11.11	87.07	1.74	.03	.04	0	0	0	99.99	72	0	......	243
4	Riverside County, Cal.........	Molding	0	.65	1.75	1.72	2.11	1.42	.44	15.98	1.15	1.36	73.35	99.93	1440	4.4 5.7 7.6 9.8	...... 180 187 184	5.2 6.1 5.6 ......
715	Vassar, Michigan..............	Core	0	0	.01	.16	7.39	54.66	24.84	8.75	3.42	.54	......	99.77	......	0	......	56
529	South Amboy, N. J...........	Steel Sand	0	.15	.83	10.86	77.74	8.73	.68	.19	.14	.22	......	99.54	76	0	......	240
531	South Amboy, N. J...........	Molding Gravel	0	1.98	7.88	31.36	36.98	3.26	1.80	.90	1.14	3.16	11.64	100.1	240	4.2 6.3 8.2 9.6	137 129 103	105 253 275 219
211	Hudson River Valley, N. Y...	Albany Grade 0 (Open)	0	.12	.04	1.04	24.68	21.94	18.30	11.98	10.24	6.10	5.40	99.84	276	3.8 5.8 7.6 9.6	115 119 118	36.5 44.0 44.5 42.0
210	Hudson River Valley, N. Y....	Albany Grade 3	.46	.96	1.32	19.14	41.56	5.26	3.08	1.86	2.96	7.60	15.76	99.96	244	4.0 6.0 8.0 10.1	146 173 127	14 68 169 133

Note: The data for this table were selected from an extensive table published by the American Foundrymen's Association giving results of tests made in the official testing laboratories of that association. See Trans. Am. Foundrymen's Asso., Vol. 32, Pt. 2.

Sand used to make cores and steel molds is commonly artificially bonded. Artificial bonding material is added either to obtain an unusually strong sand, as in the case of core sand, or because it is not possible to obtain a naturally bonded sand with the specifically desired properties for some specific use as in the case of steel sands which must have a high refractoriness not obtainable with naturally bonded sand.

A large variety of artificial binders are used for foundry sands. Each one has special advantages for specific uses. Core oils, pitch, fireclay, resin and organic powders are widely used. They all are cements which after baking firmly bind the sand much as dried glue would do.

C—Stresses, Tests and Strength Requirements of Foundry Sands

To appreciate fully the value of strength tests of foundry sands it is necessary to consider what the stresses are to which sand molds and cores are subject. In speaking of these stresses it may be said at the outset that cases where these are simple stresses, direct tension or compression, are the least important. The difficulty introduced into the study of strength of sands by the complexity of the stresses under which they are used is largely mitigated because a sand strong in compression is ordinarily strong in tension, bending, and shear; and is relatively resistant to a combination of any of these.

That a different degree of strength is required of two sands, one of which is used to make a small compact green sand mold, while the other is employed to make long, slender, unreinforced cores is clearly apparent. These two cases represent the extremes of strength required of foundry sands. Between them are all gradations.

Determination of the relation between strength of sands and the factors; kind of bond, grading of sand, its size, and the general relations of the bond to the sand are problems primarily of scientific value and which become of value to the foundry only when carefully and completely worked out. They will be relegated to the research department.

It has already been pointed out that the strength of sand is

much affected by the amount it is compacted. Studies regarding this may profitably be made to determine what variation in strength takes place with different intensities of ramming used in the foundry. Such studies would tend to standardize ramming of molds.[3] Sometimes it is of value to study how much strength can be developed by ramming before the permeability of the sand is so far reduced as to make it unfit for use. Permeability decreases with compaction, while strength is increased, and it is conceivable that the condition might arise where an overly strong sand deficient in permeability might be rammed lightly and be satisfactory for use in the foundry. The reverse of this might also arise; where a sand of high permeability but deficient strength might be made use of by extra strong ramming.

To reclaim sands they must be rebonded by the addition of bonding material and subsequent mulling. The blending of sands also requires mulling. A series of strength tests is a very definite way of telling what the benefit arising from different degrees of mulling is and whether blending and reclaiming sands is an advantage to the foundry. Blending is often done to obtain high permeability, but it is necessary in doing this to make sure the strength of the sand remains up to the value required.

A sand is no longer of value in the foundry when its bonding strength is gone. Studies of life of sands require the making of strength tests.[4]

The tests suggested in the foregoing paragraphs are possible research tests of green molding sands. They are merely suggestive applications of strength tests and by no means has the full category been enumerated. For foundry control no problem of testing is involved, simply the results of the tests are desired. Whether the sand used is up to the strength standard required is all that must be known.

As illustrations of how studies of the strength properties of

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[3] Since this was written a private communication from C. A. Hansen of the General Electric Company called attention to the studies of ramming that he has made. These will no doubt be made public before long. At the present time considerable research on molding sands is under way and it is quite probable that much data upon the subject of ramming as well as the other problems of strength testing noted in this paper have been obtained and will appear publicly in a short time.

[4] Molding sand reclamation and control experiments, Wolf and Grubb, Trans. American Foundrymen's Association, Vol. 32, Pt. 2, Page 1.

sand may be conducted the following brief instructions for carrying on tests are given.

If information is desired regarding the relation between strength and moisture content several samples of sand are selected and each tempered with a different amount of water and the true water content determined. Test specimens are prepared by ramming portions of sand from each of the samples at some standard compaction after which each specimen is tested and the results tabulated or plotted upon co-ordinate paper.

The least strength required for a certain class of work may be determined in the following manner: Set aside one floor of the foundry for observation and place on this floor a quantity of sand sufficient for the needs of the floor and not allow any new sand to be added nor any of the present sand to be removed during the test. Proceed then with normal casting operations upon this floor until through excessive failure of the molds the sand is adjudged to be of no further value. During the period of time casting operations are being carried on make periodic tests of the strength of the sand which will show the decrease of the bond of the sand and will indicate the point at which the sand is no longer fit for use in the foundry. This test would give the lowest strength of sand which could be allowed in casting the class of work carried out on the floor selected for observation. It also would give for the class of work done on the floor the number of pounds of casting which one ton of sand would produce.

As the strength properties of sand are different before and after baking, a strength study of dry sands add some features additional to those of green sand testing. Dry sand molds must have ample strength when dried as well as when green. Dry sand molding material may have artificial binder added and a study may be made of this. If any question exists regarding the strength of the sand after baking a study of baking and its relation to strength may be undertaken. Baking molds is expensive and by determining the least baking necessary to develop the required properties of the sand great economies may be made.

The studies mentioned in connection with dry sand molds are additional to those mentioned for green sand testing, in both

cases the problems of best compaction, moisture content, and bonding material are present and require study.

Core sands which owe their coherence to their content of artificial bonding material and subsequent baking present together with other sands similarly bonded, interesting possibilities for strength studies. Sand for cores is selected for its great permeability and its bonding power is very small so that some substance must be added to give it strength. Strength, however, is only required before casting and is expected that an easy disintegration of the core will take place after the hot metal has solidified around it. Problems of obtaining the required strength with a minimum amount of bonding material and with such kind that will permit disintegration after use, arise which strength tests may aid in solving. Other problems as the efficiency of various binders, time and temperature of baking to obtain the desired strength in the most economical manner arise and may be solved by strength tests. Periodic tests made of test cores prepared from the core sand mixture employed in the foundry is another application of control tests.

Steel casting foundries have been popular supporters of strength tests of sand. Their problem of making a bonded sand from one not naturally bonded and in addition obtain the required properties such as refractoriness, makes necessary strength studies and control tests. Strength tests help solve problems of obtaining the most satisfactory grade of silica sand so that a high enough strength will be obtained with the least bonding material and yet have good permeability and what mulling is necessary to develop the strength, and establish the best moisture content and compaction which is to be used in the foundry. To maintain the established strength standard requires a system of control tests for the foundry.

This is a portion of the field of testing as it has at present developed. With a wider adoption of the practice of testing which is now so well started, the field in which strength tests may be beneficially applied will be increased.

Whatever may be the immediate reason for testing, its ultimate reason must be to help decrease the cost of casting and

improve the quality of the castings. Strength testing is proving its worth in accomplishing these objects.

D—General Problems in the Preparation and Testing of Specimens and the Establishment of Standard Tests

(1) *Sampling*

Any sample of sand must be so selected as to represent the mass of sand to which the test is to apply. For example, in selecting a sand sample from a pit it should not be dug from one spot unless the pit is known to run very uniform. Instead of this the sample should be selected by carefully quartering down a large sample which in turn has been taken by trenching across the face of the pit in a number of places. Also a sample of sand taken for control purposes from the outside of a heap on the foundry floor may be too dry to be representative of the complete heap or one from the center may be too wet. Detailed instructions for sampling sand and similar materials are easy to obtain.[5]

(2) *Tempering*

In the greater number of cases sand samples are brought to the place of testing as loose sands either tempered or untempered. If the tests are control tests the sand will be already tempered, while if the tests are to be research tests it will be necessary to temper the sands in the testing laboratory according to the studies which are to be undertaken.

(3) *Compacting*

The testing of loose sands requires that they be compacted. The only case in which sand will not need compacting before testing is when the specimen is carved from an already compacted mold.

The manner in which sand is compacted is of particular

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[5] Complete instructions for sampling foundry sands are given in Volume 31 of the Trans. of the American Foundrymen's Association. See also Molding Sand Control in the Foundry, Deitert & Myler, Trans. American Foundrymen's Association, 1926, Vol. 33.

importance when a standard test code[6] is being prescribed, in which case the compaction must be so defined as to make possible its easy duplication by one wishing to employ the test. Further, the method of compaction must be convenient enough that no one will be induced to follow other means of compacting the sand which may be more convenient but less exact.

There are three general methods of compacting sand. They are to drop a weight upon top of it; to exert a steady pressure upon it; to jar or vibrate it. The hand method employed in the foundry where the sand is tamped by striking it with tamping bars is analogous to dropping a weight on the sand. Some molding machines compact the sand under a steady pressure.

Test specimens will in all cases be compacted either by dropping a weight upon top of the sand, applying a steady pressure upon the top of the sand, or by vibrating the mold containing the sand. The last method is only used for test specimens of oil bound core sands. The first method, dropping a weight on the top of the sand, has been adopted for compacting test specimens of molding sand, dried sands, etc., to the exclusion of applying a steady pressure. There have been some experiments performed upon test specimens compacted by steady pressure, but they have not as yet been made public.[7]

There are four means of measuring and expressing the compaction of a sand sample. They are: The number of foot pounds of energy per cubic inch of compacted sand that has been used in compacting it (other units may be used), the pressure to which the sand has been subjected during compaction, the density which the sand has after compaction, and a measurement of the hardness of the compacted sand made by dropping a steel ball of standard size from a certain distance upon a smooth sur-

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[6] A standard test is one made according to instructions which have been generally recognized and followed and which make tests performed by different persons in widely separated localities and working under different conditions and with different pieces of apparatus comparable. The results of a standard test must be expressed quantitatively in units which are the same or convertible to the units in which results of other tests made according to the same test code are expressed. For this to be possible the instructions of the test code must be carefully prepared and rigorously followed. The manifold advantages of standardizing tests are so obvious as to need no comment. It is as desirable to standardize foundry sand tests as it is to standardize screw threads. To be satisfactory, a standard test code requires wide recognition and by placing its prestige behind such a code the American Foundrymen's Association is performing an estimable service to all foundrymen.

[7] Private communication to the author from C. A. Hansen, Research Engineer, General Electric Company.

face of the sand and measuring the diameter of the indentation. Instead of dropping the ball from a certain height the ball may be pushed against the sand with a standardized pressure.

Where the sand is compacted by dropping a weight upon it the most convenient method of expressing the compaction is to give the number of units of work per unit of volume of compacted sand used in compacting. The work consumed in compacting the whole sand specimen is the amount of the weight which is dropped on the sand multiplied by the height it is dropped and by the number of times it is dropped. This product is divided by the volume of the sand specimen and the unit compaction obtained.

Compaction expressed in energy per unit volume of compacted sand is not convertible into compaction expressed in pressure to which the sand has been subjected. This may be expressed in another manner by stating that if several specimens of sand each of the same size after compaction are all compacted under the same number of blows of a weight which falls each time from the same height they will not each have been subjected to the same unit pressure. The converse statement is also true that if several specimens of sand of the same size after compaction are each compacted under the same steady pressure, the same unit work was not expended in compacting each of them.

This can be made clear by reference to the left hand diagram of Fig. 1. In this diagram A is a sand specimen which for the purpose of neglecting the effect friction between the sand and its confining mold has upon the compaction of sand, is assumed to be held in a cylinder which is inextensible and which causes no friction between itself and the sand during compaction. Before compaction the sand which forms this cylinder occupied a length indicated by L. After compaction it occupied only the length indicated by the dotted portion. To compact the sand, weight W was dropped on the top of the cylinder so that it fell a distance H to rest upon the top of the compacted sand. The work expended in compacting the sand is equal to weight W multiplied by distance H.

The small diagram at the right of that portion of the cylinder which was cut off by the compaction of the sand shows the force

which weight W placed upon the sand from the time it struck the sand until it came to rest upon top of the compacted cylinder. Vertical distances on this diagram indicate the position of the weight during the time it compacted the sand. Horizontal distances indicate the intensity of the pressure existing on top of the specimen from the time the weight comes in contact with it until it comes to rest.

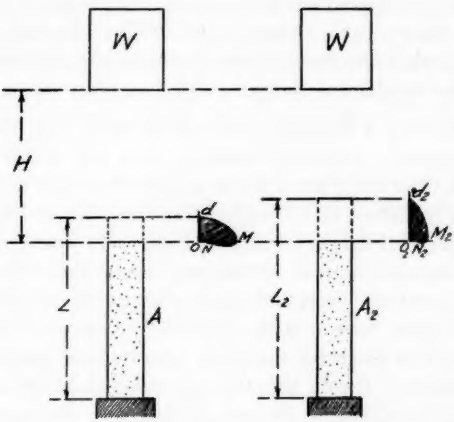

FIG. 1

At the moment the weight strikes the sand there is zero pressure, but due to the resistance the weight encounters in its downward motion, a pressure quickly builds up. Some place between where the weight strikes the sand and where it comes to rest the pressure will rise to a maximum and will then fall to the pressure which the weight causes upon the top of the sand specimen when it comes to rest. In the small pressure diagram referred to line d—o is the line of zero pressure. The pressure at the instant the weight touches the sand is indicated by d. From point d the pressure increases to a maximum when the weight has gotten as far down as m. The pressure decreases to N when the weight comes to rest on the sand. N—O is the intensity of

the pressure at this time. Sand is probably somewhat elastic, so the weight actually descends lower than its final position and there is a slight rebound. For this reason the pressure curve has been drawn below the horizontal line level with o, which indicates the final position of the weight.

The important thing about this diagram is that the area of it, when measured in the proper units, is the amount of work spent in compacting the sand and is equal to the product of the weight times the distance it fell. (Only one weight drop has been considered here to avoid complication. The conclusions arrived at by considering one weight drop would be substantiated by considering any number of weight drops.)

Consider for a moment what would have been the result if the sand selected to make cylinder A was one which decreased in volume a little more for a given weight drop than did A. Such a condition is shown by the right hand diagram of Fig. 1 where L_2 is the original length of this cylinder. In this event a little more uncompacted sand would be required to make the compacted cylinder A_2 and the height of the pressure diagram (from d_2 to o_2) would have been a little greater. However, the diagram would have had to retain the same area so that point M_2 could not have been so far to the right of d_2o_2 as M is to the right of d-o. The position of M and M_2 indicates the greatest pressures to which the sands were subjected, therefore, the two sand samples would not have been subject to the same compaction if the pressure is taken as a measure of the compaction.

Bulk density is a satisfactory measure of the compaction of a series of specimens made from a given mass of sand, but would not be valid without some means of correction when different kinds of sand are compared. It is, therefore, not suitable as a general measure of compaction but is, however, very valuable as a measure of compaction in some research tests.

As a given mass of sand becomes more moist it will compact to a smaller volume under any given weight drop or under any given steady pressure. It is thus impossible to correlate compaction measured in terms of increase in density and measured in terms of either pressure or units of work per unit volume.

Measuring the compaction of a mass of sand by the ball method is an empirical one. It, therefore, has no relation to the other means of measuring compaction except by coincidence.

From the foregoing discussion we see that the four methods of measuring density are each separate and are incapable of being transformed one into the other. It is thus necessary to make an arbitrary choice of one when the compaction part of a standard test is being formulated. Perhaps the best basis for selecting the means of compacting test specimens is to specify that it will follow as nearly as possible the method of compaction used in the foundry. The Committee on Standard Tests of the American Foundrymen's Association considered that by dropping a weight upon top of the sand and measuring the compaction in terms of units of work per unit volume of compacted sand, this had been accomplished.[8]

Some consider that compacting a sand specimen by pressing it under a steady pressure would be superior to dropping a weight upon it. This view is supported by very valid arguments.

In selecting the means employed to compact test specimens some consideration should be given to the ease with which the compaction can be acomplished. It would be quite difficult to compact a sand specimen to the same hardness as measured by the ball method, so this would not be a satisfactory procedure to write into a set of standard test specifications. Either to compact a specimen under a constant pressure or to compact it to a certain number of units of work per unit of volume is comparatively easy and as far as carrying out tests either of these two methods would be satisfactory.

Of great importance in compacting sands is the effect of friction produced on the sides of the container by the wedging action of the sand grains. This is illustrated by Fig. 2 where, on a much enlarged scale, a few grains of sand are shown in juxtaposition to one surface of the container in which they are being

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[8] The selection of compaction by the committee was not made in the terms it is here expressed. The committee specified only one degree of compaction. To so do they specified that the resulting sand specimen would have a constant size and that the same number of weight drops with the same sized weight dropped from the same height would be used in compacting the sand. Thus, consciously or unconsciously but indirectly, a constant compaction in terms of energy per unit of volume was specified

compacted. The forces they exert upon one another and upon the side of the container are shown by arrows. Due to the force acting sideways between the sand and the side of the container and to the relative movement which takes place during the compaction of the sand a retarding force made up of the forces B_1, B_2, etc., acts to prevent the downward motion of the sand and consequently its compaction.

In case a sand specimen is compacted against a solid stop there will be an appreciable difference in compaction between the top and the bottom due to the friction of the sand on the sides of the container. Fig. 3 A shows how the compaction varies through the height of a specimen compacted against a solid stop, that is to say, single end rammed. The horizontal distance from

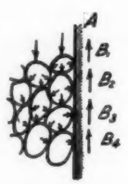

FIG. 2

the line O-O to A-B is the intensity of the ramming at any point along the specimen. As shown by the line A-B drawing in closer to O-O at the bottom of the specimen the compaction is appreciably greater at the top than it is at the bottom.

If sand is rammed in a container which is free to move relative to the stop against which the sand is rammed, the effect is the same as ramming the sand simultaneously at the two ends. The relative movement between the sands and the container is much less and the force which retards compaction is therefore less. Also the variation in compaction along the specimen is reduced. Fig. 3 B shows the variation of compaction from top to bottom of a sand specimen for double end ramming in a similar way in which this was shown for single end ramming. With

double end ramming the intensity of ramming is the same at the two ends of the specimen, but is slightly less in the center as shown by the curve A_2, C B_2 of Fig. 3 B.

The greatest difference between intensity of ramming is much less for specimens double end rammed than those single end rammed provided this comparison is made between specimens of the same form. It is usually only necessary to resort to double end ramming when the height of the sand measured parallel to the direction of ramming is one and one-half times the greatest dimension at right angles to this direction.

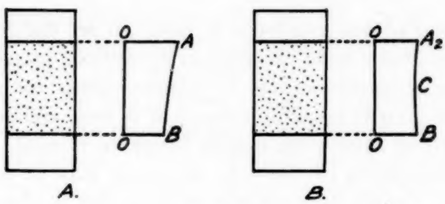

FIG. 3

To insure constant compaction for a standard test it has been found necessary, in the case of compaction by dropping a weight, to specify the dimensions of the compacted specimen, the weight to be dropped, and the distance and number of times this is dropped. Thus the same amount of work is expended on each unit volume of sand and friction upon the walls of the container has the same influence in each case, so if compaction is measured by the work expended per unit volume of sand each sample will be compacted the same amount. However, as noted before, different grades of sand or specimens of the same sand with different water content, will not be put under the same pressure.

If a sand is compacted by applying a steady pressure it will also be necessary to specify the size and form of the test specimen in order to keep the influence of friction constant. Any sand will, of course, be subjected to the same pressure when compacted in

this way, but different kinds of sand will not in general have the same amount of energy expended per unit volume.

If the sand be compacted by jolting, jarring, or vibrating it is impracticable to determine either the pressure to which it is subjected or the amount of energy each unit volume of sand has absorbed. Where this means of compaction is employed it is necessary to specify, in addition to the dimensions of the sand specimen, all of the conditions of jarring, such as time, weight of mold, weight of jarring table, kind and size of jarring or vibrating apparatus, number of jars, time of vibration, etc.

(4) *Form and Size of Test Specimen*

The kind of test employed is likely to set the form of the test specimen, but a wide variation in dimensions may be allowed. Thus for a compression test a cylinder seems to be the best adapted, for a cross breaking test, a bar is best, and for a tensile test of a strong sand some special briquette is used. For most tests the dimensions of the test specimens may be set to meet convenience, though in a number of tests this has been violated by making the test specimens too large.

In all tests where the sand is compacted, the shape and size of the test specimen should be such as to insure that the sand be uniformly compacted and that no flaws be introduced in the compacting. It has previously been pointed out that to obtain a reasonable uniform compaction with compression cylinders rammed from one end, the length should not exceed one and one-half times the diameter.

The cylindrical test specimen is universally employed for making compression tests of sand. The relation between the diameter and height of a compression cylinder has been given considerable discussion because of the problems in testing it presents. It is well known that with cylinders of the same diameter and varying length, though all are made from sand having the same true strength and each is compacted the same, the shorter one will apparently have the greater strength in the test. One reason for this is the greater effect slight, unavoidable eccentricity has with longer cylinders. Another reason is that the binding

action of the plates between which the test specimen is crushed strengthens short cylinders more than long ones.

The varying strength between long and short cylinders is another reason for specifying the form and length of the test cylinder. The question has been raised what ratio of length to diameter should be used for compression specimens, and it has been pointed out that for steel, concrete, etc., a cylinder twice as high as its diameter has been adopted. There is some justification in selecting this ratio of length to diameter for sand test specimens except that with long cylinders the compaction will be more uneven. With a test cylinder having a ratio of diameter to height of 1:1 the compaction will be quite uniform, though the strength exhibited by this cylinder will be somewhat in excess of a longer cylinder, however, consistently in excess.

The American Foundrymen's Association has adopted a test cylinder 2 inches in diameter and 2 inches high, the lesser ratio of height to diameter, because it was believed satisfactory from a scientific point of view and also because a compacting apparatus had previously been adopted which made this size cylinder for the permeability test. It was felt it would be unwise to add another compacting apparatus when the size specimen prepared with the one already adopted could be used as well as not.

A curve, Fig. 4, plotted from actual experimental results, is introduced here to show how the compressive strength of a cylinder of sand increases with a decrease of cylinder height. The tests from which this curve was plotted were performed using cylinders 1⅛ inches in diameter and which were rammed with the same number of foot-pounds of energy per cubic inch of compacted sand. Before the curve was plotted the data were corrected for the effect friction has in preventing full compaction, which is variable for cylinders of different heights. The curve, then, represents the true relation between height and strength. It shows that the strength of a cylinder having the length ratio of 1:1 is about 15 per cent greater than one having a ratio of 2:1. It further shows that the rate of change of strength with length is more rapid with shorter cylinders than with longer ones. This has a bearing upon the tolerance limits that may be allowed in the height of test specimens, now to be discussed.

It would be very inconvenient to make the dimensions of every standard test piece come exactly to that specified, so it is necessary to allow some variation in size. The amount of variation allowed is called the tolerance. This is limited so that the accuracy of the test is not seriously affected. With cylindrical compression specimens the diameter is set accurately by the diameter of the cylinder in which the specimen is rammed, but some tolerance in length must be allowed. The curve of Fig. 4 shows that as the ratio of length to height for the compression

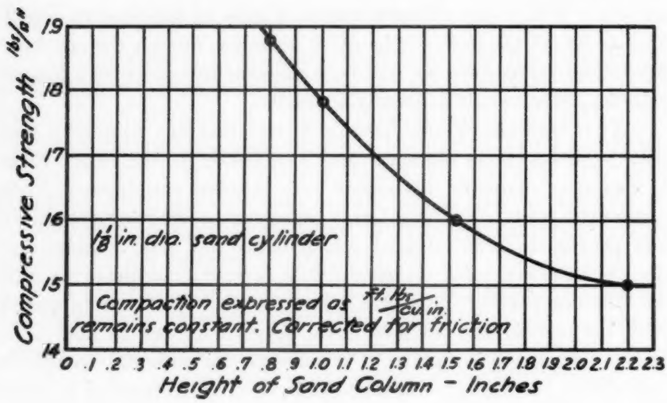

FIG. 4

test cylinder is made less, a given tolerance in length will permit a greater error in the results of a strength test. It is thus an advantage in the matter of tolerance to use a test cylinder which is long relative to its diameter.

In considering what tolerance should be allowed in the length of cylinder for the compression test, a curve similar to the one shown by Fig. 5 is valuable. This curve is plotted between compressive strength and length for a cylinder of constant diameter. The cylinder used in the tests was 2 inches in diameter and the plotting was made from actual experiments. This is the size sand cylinder that has been tentatively adopted by the American

Foundrymen's Association for their compression test. The curve extends over a range of length of from 1.7 to 2.4 inches while the exact 2 inches is the length specified for the A. F. A. cylinder. The tolerance limits for the A F. A. cylinder are .08 inches either way from the exact 2 inches and these limits are indicated in Fig. 5.

The curve of Fig. 5 differs from that of Fig. 4 not only in size of cylinder and the kind of sand used in making the experiments but also in that the same total energy of compaction was

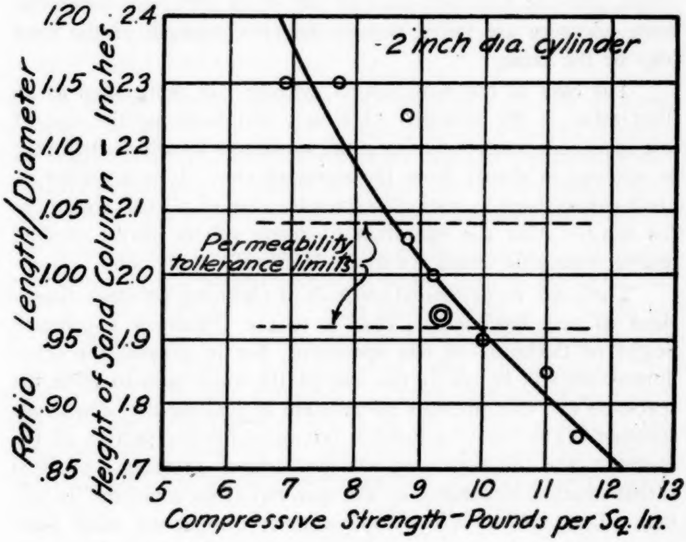

FIG. 5

used in all the experiments of Fig. 5 while the energy of those of Fig. 4 was varied so as to keep the unit energy of compaction constant. Also no correction was made in the case of the experiments of Fig. 5 for the effect friction between the sand and the sides of the cylinder has in decreasing the compaction. Therefore, the plotting of these shows the total difference in strength between cylinders of different length when it is intended in the test code

that these shall be of one length. Also the error introduced by a cylinder departing from the intended length as much as the tolerance limits allow is shown. This error, as has been indicated above, is due to three influences; first, difference in length alone; second, lower or higher unit compaction due to greater or lesser amount of sand which has to be compacted; third, lower or higher compaction due to the greater or lesser friction effect. These three influences are cumulative and as shown by Fig. 5 a difference of 14 per cent may exist between the indicated strength of a sand when cylinders 2 inches in diameter and 2 inches in length plus the tolerance limit of .08 of an inch and minus this same tolerance are tested though the true strength of the sand may be the same.

The case of the compression cylinder has been taken as an illustration of the necessity of closely standardizing the size of test specimens and specifying small tolerances by which they may be allowed to depart from the standard size. It is a matter of great convenience in testing to have the size of all test specimens the same. Also the operation of many of the direct reading testing apparatus which are to be described require this.

There are three general methods of obtaining constant dimensions of test specimens. That is to say, obtaining a constant height or thickness of test specimens, for in general the other dimensions will be set by the size of the mold used to form the specimen and this presents no problem in making the dimensions constant. The top of a mold is left open for compaction of the specimen and the dimension whose constancy presents a problem is that which is terminated by the open top of the mold and its bottom. The problem is the same whether compacting takes place by ramming, pressing, or vibrating Some space in the mold must be provided in excess of the space occupied by the compacted sand to provide room for the sand in its loose condition before it is compacted.

One means of obtaining a constant height of the compacted specimen is to put exactly enough loose sand in the mold so that when this is compacted it will shrink to the desired dimension. This is the only way to insure constant height and at the same time secure constant compaction For convenience, however, it

requires that some tolerance in height be allowed. It is the manner most commonly employed and the one adopted by the American Foundrymen's Association for all its tests requiring the compaction of sands. With this method of compaction the selection of the right amount of sand is a guess and if the first specimen, after compaction, is not of the proper size (its length must lie within the tolerance limits) it must be discarded and a new supply of sand taken to make a second trial. This must be repeated until the proper size specimen is obtained. With some experience in testing sands the first specimen may be made to come within the tolerance limits and it is unusual to be required to make more than two.

A second manner in which constant height may be obtained is to compact a mold full of sand, then trim the specimen down to the desired height. This does not insure constant compaction and, further, the trimming is liable to flaw or disturb the structure of the test specimen so that the test results are not fully reliable.

A third means of obtaining a constant dimension, admittedly a variation of the second and open to the same criticisms, is to have a mold separated at the point where the limit of height of the specimen is to be. Before and while ramming the mold it is held together by dowels and clamps or some other means. The mold is filled with sand, rammed, and after ramming is separated and the surplus sand struck or scraped off. The top part of the mold has been called the surplus frame, therefore, this method may be called the surplus frame method of obtaining constant dimensions.

The surplus frame method of obtaining constant height is particularly adapted when oil bound core sands are compacted by vibration Here the amount of compaction is somewhat indefinite and in a slight degree less important than with water moistened sands and the sand will stand striking off better.

Test specimens may be cut from a mold prepared in the foundry when it is desired to determine the strength of sand under true foundry conditions. To do this a large chunk should be broken out of the mold and trimmed down carefully. If any flaws develop during trimming a new start must be made.

(5) *Rate of Loading*

The rate at which a test specimen is loaded may influence the strength obtained in the test. Usually when the rate of loading is greater the strength obtained is higher. This is due to the fact that a specimen of sand which is not a brittle substance does not break suddenly and will momentarily sustain a load beyond its true breaking strength.

The Sub-Committee on Standard Tests of the American Foundrymen's Association found it necessary to specify in the case of their bar test (later to be described) the rate the bar is pulled over the edge of the plate on which it lies and which is the means adopted for stressing the sand. This is equivalent to specifying that the rate of loading of the sand takes place at some definite (though in this case not uniform) rate.

Some experimental results upon the effect of the rate of loading upon the strength of test specimens indicated by tests of compression cylinders are given by Table 2. The tests were made on a hydraulic type apparatus and the rate of loading was measured by the turns per second given to the handle of the apparatus.

Table 2

Rate of Loading Turns per second of screw	Strength of Sand Specimen Pounds per Sq. Inch
1	2.9
1	2.7
1	2.6
3	2.4
3	2.5
3	3.0
5	2.8
5	2.8
5	2.6
5	2.8

One turn per second is as slow as any one would care to turn the handle of the apparatus used in the test and five turns per second is as fast as one can turn it by hand. The indications from these tests point to the conclusion that rate of loading has but little influence upon the strength, at least, within the limits of

rate of loading that an operator will produce when working a hand operated apparatus

(6) *Point of Failure*

It is sometimes difficult to tell exactly at what point a sand test specimen has failed Most sand specimens will suddenly go to pieces with little deformation when their breaking strength is reached, but a few green, tempered molding sands show a marked deformation before they fall to pieces and during their deformation the pressure upon them is gradually increasing. Whether or not the sand has failed when a certain amount of deformation of the specimen has taken place is a point in question. It would seem safer to consider that after there has been a marked deformation and a really plastic flow has taken place the specimen has to all purposes failed. The amount of deformation allowed must be set arbitrarily if a limit is adopted. By far the largest number of sands do not flow so badly but that the point they fall to pieces may be considered with safety to be their breaking point. Apparatus has been devised for indicating when a certain amount of deformation has taken place and has been used in tests where it was stipulated that the sand had failed after the deformation reached some specified amount.[9]

A suggestion has been made that the characteristic exhibited by a sand in deforming under load without falling to pieces is an important indication of the use to which it is adapted. There is no information available at present to substantiate this suggestion and for the present it must remain a matter for future investigation.

E—Interpreting Results of Tests in Terms of Foundry Practice

The immediately adaptable purpose of research tests is to determine what properties of sands fit certain uses best. As a part of conducting tests, close connection should be established between the tests and the uses to which the sands are found adaptable in the foundry. At present there is much indefiniteness regarding to what use a sand may be put after all known labor-

[9] This is the practice of C. A. Hansen, research engineer for the General Electric Company.

atory tests have been applied and the data are available to render a decision. We wish to know at present just what are the strength requirements placed upon sand for different foundry uses. So, in making molding sand tests, alongside of the test data a complete description of the use to which the sand is put and notes stating how successful the sand is fulfilling the needs this use represents should be available. A full knowledge regarding foundry sand will never, like the knowledge in any other field of science or art, be completely obtained. At present our knowledge of molding sands and the properties needed in them to fulfill certain wants is very meager, but with careful study by tests and observation of what results are obtained in the foundry, a store of knowledge will be built up which will be the basis upon which better workmanship and great economies in the foundry may be founded.

Part 2

APPARATUS USED IN MAKING STRENGTH TESTS OF FOUNDRY SANDS

A—Introduction

Because of the weakness of sand test pieces, they cannot be tested with ordinary testing apparatus used in testing laboratories for making compression, tensile, and transverse tests of other substances. These lack the delicacy required to measure with a sufficient degree of accuracy the small forces employed in testing sand specimens. Further, because of the weak nature of compacted sand, it is desirable to employ some modifications in ordinary testing methods.

Green molding sand is the weakest of all material tested; and as its strength range is much below that of baked sands the apparatus employed to test these two kinds of foundry sand must in some cases be different in order to obtain a suitable delicacy of measurement and in order that a suitable testing procedure may be developed. Sand used in dry sand molding (where the sand is baked) falls, before baking, in the strength range of molding

sands and when it is desired to test it in this condition the molding sand tests are applied.

The kind of apparatus used to prepare the sand specimen is as important as that required to make the test. For all tests mentioned in this paper the apparatus for preparing the sample will be described and its use fully explained. The arrangement used here, to present testing apparatus, will be to take the several tests performed on foundry sands in their order and treat under the heading of the test and the apparatus which may be employed to make the test. The description and explanation of apparatus employed in preparing the sand sample for testing will precede that of the testing machine proper. Several of the apparatus which will be described can be used for more than one test by the employment of attachments. In these cases, under the discussion of the second test, a description of the attachment and of its use will be added.

The apparatus described in this paper are those which have been used for testing sands or have been suggested for this use. They are by no means the only ones that can be used, and a development of new testing apparatus is constantly in progress. Many of the apparatus might be improved materially and a more satisfactory apparatus result by incorporating the features of one with those of another. The features which adapt an apparatus for its use are ability to give the information desired, ruggedness, speed of operation, and accuracy of results. As has been mentioned, for shop use ruggedness and speed of operation are greatly desired and accuracy may to some extent be subordinated. For research laboratory work, accuracy is of prime importance.

Apparatus adapted for use in the foundry may be designated as control apparatus, a name which has grown up due to their use for this purpose. Other apparatus may be designated research apparatus. Some apparatus will, of course, be better adapted to one use than the other, while some will serve the purposes of both equally well.

B—Compressive Tests of Green Molding Sand

In the case of all the apparatus proposed for making compressive tests of green sands the test specimen employed is a small

cylinder of compacted sand. The dimensions of this cylinder vary, but in view of the fact that the American Foundrymen's Association has adopted one two inches in diameter and two inches high these dimensions are most widely used.

The cylinders may be compacted in either a split cylinder (in which case the two halves of the cylinder are clamped together while the cylinder is being rammed and can be separated to release the sand specimen) or may be rammed in a cylinder which is not divided and pushed out of this with a pushing bar. The latter method has proved more satisfactory than the former and is used in all except special cases.

All of the apparatus used at present for ramming sand specimens do this by dropping a weight upon a ramming head which rests on top of the sand. It is believed by some that it would be better to use steady pressure in ramming sand specimens but as yet no apparatus has been proposed to do this.

The following apparatus for making compressive tests of green molding sands are described; shot and beam apparatus, makeshift apparatus, toggle joint apparatus, moving weight apparatus, swinging weight apparatus, moving fulcrum apparatus, and the Dietert hydraulic apparatus. All except the last were designed to employ a test specimen two inches in diameter and two inches long. The latter was originally designed to employ a test specimen about two inches long and 1⅛ inches in diameter. Later some of these apparatus were built to use a specimen two inches in diameter.

Only two apparatus are described for preparing the sand specimen; they are the American Foundrymen's Association permeability rammer and the Dietert rammer. Another apparatus which may be used for ramming a compression test specimen is described in a paper by the author previously published.[10] This apparatus is a very simple one to make, though it is not particularly convenient to operate, and is intended only to serve the purposes of one who wishes to assemble some crude apparatus for making a few tests. It prepares a sand specimen in every way

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[10] "Testing molding sands to determine their permeability." Trans. of the American Foundrymen's Association. Vol. 32, Pt. 2. The apparatus is referred to in the paper as a "special apparatus."

similar to the one adopted by the American Foundrymen's Association.

The A. F. A. rammer is the same as that used in the permeability test. It may be used to prepare the sand specimen for all of the compression apparatus described except the Dietert apparatus when this is built to use the smaller diameter cylinder.

The Dietert rammer has certain features, beside making a smaller sand specimen, that make a description of these valuable. This rammer is used to prepare the specimen for the Dietert testing apparatus when a small diameter cylinder is used.

The compression test of sands is one of the most easily performed tests and requires but little time to carry out. Some of the apparatus described for making this test are much quicker in operation than others, as the breaking stress can be read directly upon a scale which is part of the apparatus. These apparatus are the ones best adapted for continuous control purposes.

Any of the apparatus described here which employ the same size cylinder which is made in the same manner will give comparable results for the strength of sands tested by their use.

(1) *American Foundrymen's Association Rammer*

Where a laboratory already has an A. F. A. permeability rammer it is convenient for this to be used in preparing the compression test specimens. Using the same size specimen for both permeability test and compression test makes this possible and also permits the operator to determine the permeability of the sand sample and then push the specimen out of the cylinder in which it was rammed and determine the compressive strength of the same specimen. This saves considerable time in testing. Reasons such as these have led to the adoption of a similar specimen for the permeability and compression tests by the Sub-Committee on Standard tests of the American Foundrymen's Association.

The preparation of the compression test specimen does not differ in any way from the preparation of the permeability specimen except the specimen must be removed from the cylinder in which it is rammed. A drawing of the rammer used to prepare

the specimen is shown by Fig. 6. The rammer consists of a rod A free to slide vertically in two guides, C and D, which are supported by the rammer frame B. Weight E (of four pounds) is free to slide on rod A, but with its motion limited to two inches by stops I and J. Ramming head H is fastened to the lower end of rod A and is small enough to slide freely in sand cylinder M, which is shown at the right of the rammer. A steel plug K is provided which slips in the lower end of M to retain the sand while M is being filled and while the sand is being rammed. A scale L is fixed upon the top of the frame of the rammer. This scale has

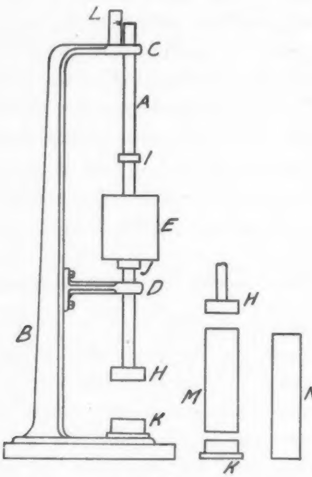

FIG. 6

three graduations ⅛ of an inch apart. They are so placed that when steel plug K is placed on the base of the rammer under the ramming head and this is held so that its bottom face is exactly two inches above the top of plug K, the middle graduation is at the same level as the top end of rod A.

To make a compression specimen, plug K is placed in the lower end of cylinder M and enough moistened sand placed in M to make a specimen exactly two inches high after ramming.

The amount of sand must be selected by trial. M is then placed under the head of the rammer and this is allowed to rest down on the top of the sand and weight E is raised until it touches top stop I and is allowed to fall, which is repeated a second and third time. Scale L is then noticed to see if the top end of A lies within the two outermost marks of the scale, which are the limits which set the amount the height of the specimen may depart from two inches. If the end of A does not lie between the two marks a new lot of sand must be selected and another specimen made.

When a satisfactory specimen is rammed, cylinder M is removed from the rammer and plug K taken from its bottom. The sand specimen is pushed from M by the use of a cylinder of wood N, which is a little longer than cylinder M and small enough to slide inside it. Cylinder M is smooth on the interior and the sand specimen slips out of it very satisfactorily. If the sand specimen is in any way cracked or marred it should be discarded and a new one made.

The compression test is very sensitive to the length of the specimen, so for accurate work (within 10 per cent accuracy) the length of the specimen must be made to come nearer to two inches than the tolerance allowed in the permeability test.[11]

The specimen, after preparation, may be tested on any one of the following apparatus.

(2) *Beam and Shot Apparatus*

The principle of operation of this apparatus is to progressively load one end of a beam by running shot into a pail hanging from the end and by so doing produce a force on a sand specimen situated at the other end of the beam which will finally break the specimen. An apparatus working on this principle of operation has a high degree of accuracy when properly constructed but they are slow in operation and bulky. It is possible to build them in a variety of simple forms and they are, therefore, well adapted to the needs of one who wishes to rig up a temporary apparatus to make a few tests.

[11] In regard to this see Fig. 5 of the first part of this paper.

For a permanent use a substantial design will be employed and a design of this nature has been adopted for description here. Fig. 7 is a line drawing of the apparatus.

The essential parts are a beam A supported by a knife edge B resting upon the top of post C. A shot pail M hangs from a knife edge on the left end of beam A. Shot running through a spout from a shot supply bin O into pail M applies the load. When the load in M becomes great enough to break the test specimen the left end of the beam drops and strikes a shut-off mechanism at N which stops the flow of shot.

The apparatus shown in Fig. 7 may be used either for tension or compression tests. The attachment used in the compression test will be described here.

The compression attachment for the apparatus consists of a sling built of a base I large enough to allow the compression cylinder to set on it and with a circular mark inscribed on its top to aid in centering the specimen, and two side arms, one of which is shown at O. At the top, the side arms are attached to two light steel bands which run over two segments, one on either side of the main beam of the apparatus as shown at D. These segments are so formed that they center on the line of knife edge B. An arm P extends to the right of main post C, of the apparatus and a screw is threaded through the end of this. The head of the screw is shown at J and the lower end supports, by means of a ball and socket joint, top plate K which bears against the sand specimen.

To make compression tests the tension attachment is removed and a weight set on the right hand side of the beam which will restore the balance of the apparatus. The prepared test specimen is then placed on I and the head of the screw turned down, bringing K on top of the specimen. This is continued until, with a little weight in pail M, the beam of the apparatus is about level. Shot is allowed to run into pail M until the sand specimen breaks, at which time the shot stream will be automatically cut off.

The weight of shot in the pail then represents, when multiplied by the lever ratio, the total pressure required to break the sand specimen. The lever ratio is the distance from the main

knife edge B of the apparatus to the knife edge from which pail H hangs divided by the distance from the main knife edge to a point on the beam even with the bands which support the sand specimen.

If the beam is balanced before pail M is hung from it, the pail and shot should be weighed together. If the beam balances with pail M hanging from it, the shot alone should be weighed. Weights should be taken in pounds and hundredths and dimensions in inches and hundredths. By driving the total pressure

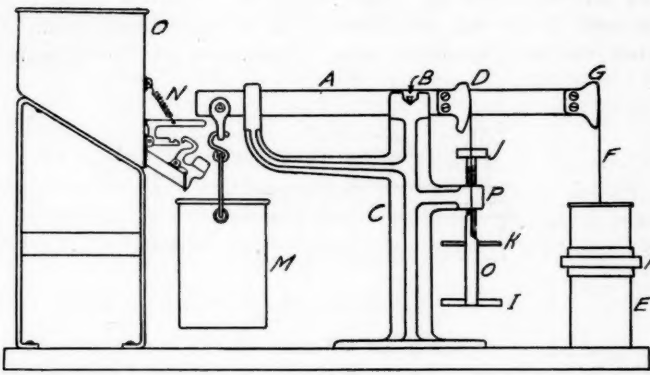

FIG. 7

on the sand specimen when it breaks, by the area of the specimen (which will be 3.14 square inches if a two inch in diameter specimen is used) the breaking strength of the sand in pounds per square inch will be obtained.

(3) *Special Compression Apparatus*

An apparatus which may be used to make a few compression tests of green sands is shown by Fig. 8. This apparatus can be easily and quickly made in any workshop.

It consists of a stick of hard wood A about 20 inches long and 1 inch square. The stick is pivoted at B to a post which is

bolted to a wooden base F. Pail C hangs in a notch cut in A which is 18 inches from the point this is pivoted, B.

Sand specimen D rests on a plate E and has a small plate G on its top. G is a circular plate ⅜ of an inch thick and is just about two inches in diameter. A short bolt is screwed into the middle of the top face and the head of this is ground to a semi-spherical shape.

Two marks are made on the side of beam A, one, J, is 4½ inches from pivot B and the other, K, is 9 inches from this point. The sand specimen is placed even with either one of these marks and directly under the center beam A. A wood block I is fastened to the base as shown. This serves to catch beam A when the sand specimen fails. Dimensions of the apparatus

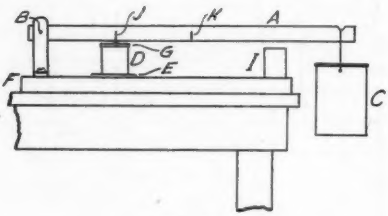

FIG. 8

which have not been specified should be made such that beam A is level when the sand specimen is in place and ready for the test to be made. As additional equipment for this apparatus about 20 pounds of shot, a scoop, and a pair of scales are necessary.

To operate the apparatus the sand specimen is set on plate E and plate G is set squarely on top of the sand specimen. Beam A is then raised sufficiently to allow the plates with the specimen to be slid under it and is then allowed to rest down upon the bolt head in plate G. If a sand appears strong, the specimen should be placed under mark J (4½ inches from B), otherwise it should be placed under mark K (9 inches from B). In either case it should be centrally placed under the beam. With the sand sample in place and the beam resting on it, shot is

poured slowly and at a uniform rate into pail C until the sand specimen breaks. The pail is then removed and weighed and the breaking strength of the sand computed.

If the sand was placed at joint J the breaking strength is found by adding the weight of plate G, twice the weight of beam A, and four times the weight of pail C, including the shot in it. This sum is divided by the area of the sand specimen. The weights should be taken in pounds and hundredths and the area in square inches, then the strength computed will be in pounds per square inch.

If the sand specimen was placed at a point K, the weight of plate G, the weight of the beam, and twice the weight of the pail and shot should be added and the sum divided by the area of the specimen.

The apparatus may be built for any size sand specimen. A 2x2 inch cylinder will be found satisfactory and convenient to handle.

An apparatus employing the same principle as the special apparatus described here but more substantially built and intended for continuous use is described by C. A. Hansen in a paper published in the Trans. of the American Foundrymen's Association.[12]

(4) *Toggle Joint Compression Apparatus*

An apparatus which works on the principle of the toggle-joint is shown by Fig. 9. This apparatus is especially adapted to compression tests and as shown in Fig. 9 is fitted for this test. The toggle-joint principle makes it possible to indicate the force on the sand by means of a pointer and scale and to have a scale which has widely spaced divisions for low pressures and closely spaced ones for high pressures, making the percentage accuracy over the range of force the apparatus is used somewhere nearly the same at every place.

As shown in Fig. 9 the sand specimen (a cylinder) is placed between plates A and B. Plate A is a bearing plate held by a ball and socket joint so that it will give an even bearing on the end of the sand specimen. Plate B is fastened to the end of a

[12] Physical Properties of Foundry Sands, Trans. American Foundrymen's Association, Vol. 32, Pt. 2, Page 57.

rod which slides in block C. The other end of this rod is fastened to a separator which spaces bar D from a like one back of D not shown in the drawing. This spacer has rollers on it so that the lower end of D may move to the right or left with a minimum of friction. The rollers run on a track fastened on top of the block upon which C is placed.

Bar E and the one behind are similar to bar D and the one behind it. These four bars are pivoted on the axis of the cylindrical weight F and support this weight.

Screw H pushes against the middle of a spacer at the lower end of bar E similar to the one at the lower end of D and similarly provided with track and rollers. By turning crank I, rod H pushes the lower end of E to the left or allows it to run far-

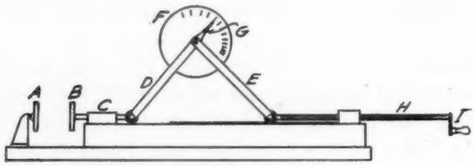

FIG. 9

ther to the right depending on the direction I is turned. Weight D acting downward pushes the space rods outward. At one end this thrust is taken through the rod which runs through guide C to plate B and thus to the sand specimen and the amount of the thrust depends upon the angle between bars D and E, becoming greater as this angle increases up to 180 degrees. The angle between the bars and consequently the pressure on the sand sample may be varied by turning screw H in or out. Weight F is fastened to bar E and turns with it. A pointer G is fastened to bar D and turns with it and indicates upon a scale inscribed on the side of weight F. This scale is calibrated in pounds per square inch pressure on the sand specimen.

To operate the apparatus screw H is turned in (turned so it will move to the left) until this raises weight F to nearly as

great a height as it will go and makes the angle between bars D and E small so that the thrust at B is also small. The sand specimen is then placed between A and B by pushing B back and then allowing it to come forward to rest against the sand specimen as this is held between the plates. The small initial pressure retains the specimen in place. Screw H is then turned out, letting weight F descend and increasing the pressure on the sand specimen. As this is done pointer G is observed and the reading noted at the moment the sand sample collapses. This reading gives directly the strength of the sand.

(5) *Traveling Weight Apparatus*

An apparatus similar in some respects to the beam and shot apparatus already described is shown by Fig. 10 and like it is adapted to either compression or tension tests or both. The

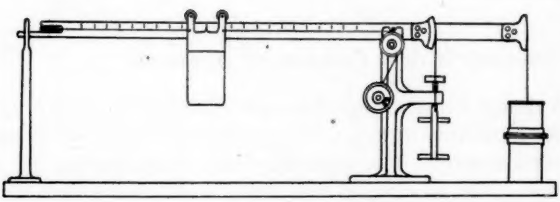

FIG. 10

compression attachment is similar to that described for the beam and shot apparatus and requires no additional description here. The traveling weight apparatus has, however, a very much more convenient method of applying the load to the sand specimen than does the beam and shot apparatus. The traveling weight apparatus is quick in operation and quite accurate. It is a somewhat bulky apparatus for the beam must be made quite long in order to give the required accuracy with sands of low strength and yet have a range of capacity sufficient to test sands of high strength.

To the left of the central pivot the main beam carries a weight on rollers which runs from near the pivot to near the

end of the beam. The apparatus is rigged with a shaft and crank from which lines run to the weight, so that by turning the crank the position of the weight many be controlled. These lines are placed so that tension in them has no effect on the balance of the beam. A scale is calibrated on the beam and a pointer carried by the weight indicates on the scale.

To operate the apparatus the weight is run to a position near the central pivot and the sand specimen placed in position on the sling, then the weight is made to travel away from the pivot by turning the crank and this increases the load on the sand sample. When the sand sample breaks, the scale indication of the pointer carried by the weight is read. The scale is calibrated in pounds per square inch stress on the sand specimen.

The scale of this apparatus is a uniform one. Later in this paper the tension test attachment will be described and it will be shown how one scale may do for both the tension and compression attachments.

(6) *Swinging Weight Compression Apparatus*

A design for a swinging weight apparatus is shown by Fig. 11. An apparatus of this type is particularly adapted to making compression tests. The apparatus has the advantage of quick operation. The accuracy is best when sands having high strength are being tested.

The principle of operation is that a weight at the end of a pivoted lever is counterbalanced by the force on a sand specimen which is held at a constant lever arm length. As the weight swings outward its leverage is increased so there must be a larger force on the sand to counterbalance the weight. The angle the weight swings outward measures the force on the sand specimen.

In Fig. 11, A is the frame of the apparatus. At its top is a shaft E carried in a ball bearing and upon which the forked lever B swings, also at this point is an extension to the frame through which screw K is threaded. Both branches of B are extended to form arcs of circles with their centers on the center of shaft E. A sling built of a base F and two side pieces, one

of which is shown at I, is suspended by two light steel bands, one shown at H, from the arcs at the ends of the two branches of B.

The other end of B carries weight C. A scale is inscribed on arc D and a pointer attached to B indicates on this scale. L is a rubber stop against which C swings when the sand specimen breaks.

Plate G is fastened to the lower end of screw K by means of a ball and socket joint which permits K to turn independently of it. K is provided with a crank J.

The prepared compression specimen is placed on plate F

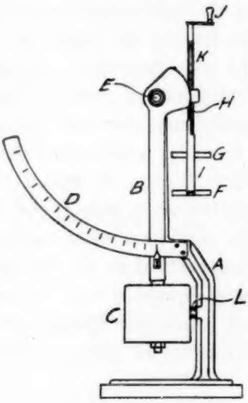

FIG. 11

and plate G is lowered on it by turning down screw K. As the lowering of G is continued, weight C is forced to swing outward and the sand sample is stressed. During the time the screw is being turned the pointer attached to B is watched and the reading it indicates is taken at the moment the sand sample breaks. When the sand sample breaks weight C will swing back. Scale D may be calibrated in pounds per square inch stress on the sand specimen so that the reading taken as the sand sample breaks is the true strength of the sand sample and no calculation is required to obtain this.

Weight C is held to lever B with a nut so it may be removed and another different weight substituted. By this means the apparatus may be made accurate over a wide range of strength and is adapted to handle very weak sands as well as very strong ones. Where an additional weight is provided for the apparatus it is made of such heaviness that the scale on arc D indicates some multiple of the true strength of the sand.

(7) *Traveling Fulcrum Apparatus With Compression Test Attachment*

An apparatus shown by Fig. 12 was developed in the sand testing laboratory and the mechanical arts department at Cornell University for use in testing all kinds of foundry sands. As represented in Fig. 12 it is provided with the attachment which enables it to make compressive tests of green molding sands. In addition to the attachments for this test attachments are provided which enable it to make tensile tests of green molding sands and tensile and transverse tests of baked core sands and dried sands. The ability of the apparatus to perform this variety of tests makes it a nearly universal sand testing apparatus. It has so far been thought impractical to fit the apparatus with attachments for making cross breaking tests of green sands or compressive tests of dried sands and baked core sands. The apparatus as described here is in the form it has been constructed in the shops of Cornell University.

It operates upon a principle which has never been used before in testing machine design as far as the author knows. This principle, that of shifting the fulcrum of a beam which has a constant force applied at one end so that the force at the other may be varied, gives the apparatus certain advantages for the testing of foundry sands which will be pointed out in the description of the apparatus and comments on its operation which follow.

In Fig. 12, A is a beam which is balanced over a moving fulcrum consisting of a wheel B and carriage C which supports the wheel. At the right end of the beam a weight D of about two pounds is fastened. The other end of the beam is forked

and bears upward against a knife edge E which is thrust through holes in the forked ends of the beam. The knife edge is carried by a post F which is supported by the pantograph arrangement G. This confines the post (through limited range) to practically straight up and downward movement. At the upper end of the post is a shoulder and above this a rod of somewhat less diameter than post F projects for a short distance so that base H may be slipped over it and held there. Pan I is slipped over the top of the post under base H.

Plate J is supported by the gallows from K and screw L, so that by turning the finger wheel of L the plate may be lowered upon the top of the sand specimen. It is intended that in

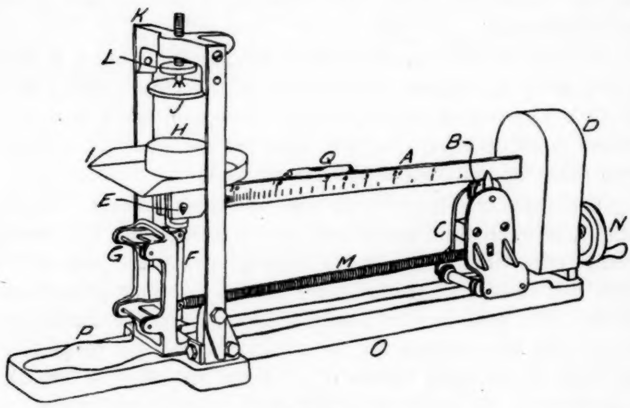

FIG. 12

preparing a weak sand specimen for this apparatus it will be rammed in a cylinder and pushed out by using base H on the end of a pushing rod for this purpose, then without touching the sand sample the base can be lifted from the end of the pushing rod and replaced upon the top of the post. Frame K may be swung back, leaving clear room for this to be done. A stop at the lower end of the wide rods of the frame prevents it from being pushed too far back and stops it in the correct position

when it is swung forward into position for the lowering of plate J. The possibility of placing a weak sand specimen in the apparatus without the necessity of the operator touching it is a decided advantage when sand specimens are tested which will crumble when taken between the fingers or when handled with tongs.

A long screw M turned by hand wheel N moves the fulcrum carriage. This screw is supported by the fulcrum carriage and a post at the right end of the base of the apparatus. The screw is a double pitch screw and so it moves the carriage with considerable rapidity. The fulcrum carriage runs on two rails cast on the base of the apparatus. An extension P to this base is provided at the left end for use with other attachments. Also a lug is cast integral with the cross piece at the top of the gallows frame and extending to the rear. This lug is used with the tensile test attachments.

In order to successfully operate the apparatus beam A must be level while the fulcrum is being moved. To insure this, a level vial Q is attached to the top of the beam and when plate J is screwed down on top of the sand specimen the specimen is forced down until the vial indicates the beam is level.

The apparatus operates in the following manner. As the distance between the fulcrum and weight D becomes greater the leverage effect this weight has in tending to raise the post against which the other end of the beam presses becomes greater and greater. The post in turn presses upward upon the sand specimen so that the distance the fulcrum is moved is a measure of the force on the sand specimen. A scale may thus be attached to the side of the beam or etched upon it as shown in Fig. 12 and a pointer may be fastened to the fulcrum carriage which indicates upon the scale the force upon the sand sample. The scale is calibrated in pounds per square inch.

One of the advantages of this apparatus lies in the distribution of the scale divisions. The scale is not a uniform one, that is to say, division marks representing the same interval of stress on the sand are not the same distance apart. For low stresses the divisions for one pound per square inch stress on the sand specimen are far apart while for high pressures the divisions for the same interval of pressure are quite close to-

gether. This has the effect of making the useful range of the apparatus very much greater than it otherwise would for the same sized apparatus and substantially the same accuracy can be obtained when testing weak sands as when testing strong sands.

To operate the apparatus as a compression apparatus, the compression specimen is placed upon base H (or as was explained before, when weak sands are being tested this base is removed and used to push them out of the ramming cylinder, then placed with the sand specimen on it in the apparatus) and plate J is lowered until the level vial Q indicates that the beam is level. Wheel N is then turned, moving fulcrum carriage C to the left. At the moment the sand sample breaks turning is stopped and the scale reading noted, after which the fulcrum is returned to the right side of the apparatus by turning N in the opposite direction. The scale reading noted is the strength of the sand in pounds per square inch.

(8) *Dietert Rammer*

This rammer is similar to the permeability rammer except in its dimensions and so needs no description. However, the cylinder in which the specimen is rammed and the block against which the ramming is done are novel. They permit rapid preperation of the sample which is of great importance where a large number of sand specimens are being tested as in the control work of a foundry.

The cylinder and base are shown by Fig. 13. The cylinder is a plain steel cylinder with the interior reamed smooth. The base B is of such a diameter as to easily slip inside the cylinder and is long enough to extend all the way through it. The base is enlarged at the bottom so it will stand steadily on end. Three or four holes are drilled through it at right angles to the axis and near the top. They are about 3/8 of an inch apart and the first one is about an inch from the upper end. A wire C having a loop at one end and which slides through one of the holes is provided.

To make a sand specimen with this apparatus the wire is placed in one of the holes of base B and the base is thrust as far into the cylinder as the wire will permit. The cylinder is then

loosely filled with moist sand. After some experience with any particular sand the proper hole, in which the wire should be placed in order that when the cylinder is filled with loose sand and rammed the resulting sand specimen which has the proper length, will become known and as this hole will be selected always thereafter when making the sand specimen of that particular sand the proper length of this is assured for the first trial.

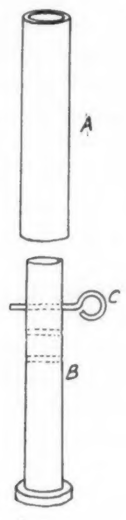

FIG. 13

After being filled the cylinder is loosely struck off at the top with the finger and placed under the rammer and the ramming head allowed to rest down on the sand. The wire is then removed and the rammer weight raised and allowed to fall. With the rammer used the weight and distance it falls are so proportioned that one drop is all that is required to compact the sand. It should be noted that the rammer gives double end ramming, for the base is loose in the cylinder after the wire is withdrawn and is free to push farther in, it therefore presses on the sand

with a force equal to the force of the ramming head. Double end ramming, which produces a more even compaction, is very desirable where a long narrow sand specimen is being made.

After compaction the sand is pushed out of the cylinder, using base B for this purpose.

(9) *Dietert Hydraulic Apparatus*

The hydraulic piston principle has proved adaptable to test-

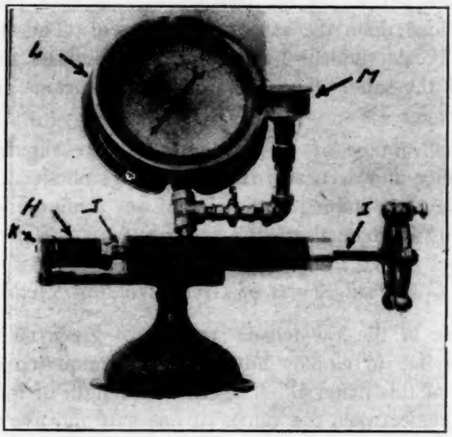

FIG. 14

ing machines and has been used in many different kinds. Recently this principle has been applied with much success to an apparatus for testing moulding sands devised by H. W. Dietert of the U. S. Radiator Corporation. Mr. Dietert described his apparatus as follows:[13]

"The test machine (Fig. 14) consists of a screw plunger I which upon turning creates an oil pressure on the oil floating pis-

[13] Commercial Application of Molding Sand Testing, H. W. Dietert, Trans. American Foundrymen's Association, Vol. 32, Pt. 2, Page 24.

ton J. At the head of this piston J, and at the end rest K, are mounted ball socketed bearing plates to equalize load application on the test specimen. The oil pressure on the piston J, or that which is supported by the sand specimen, is indicated by gage L in pounds per square inch strength of the sand. The cup M is used to replenish the oil supply in the system.

"The procedure of the test after the specimen is placed in the test machine is as follows: The hand wheel of the screw plunger I is turned by hand at the rate of 40 R. P. M. Consistent test readings are easily obtained by this hand operation. As the hand wheel is turned the oil pressure will increase, producing an increasing load upon the sand test specimen. The specimen of sand will break suddenly when the load reaches the ultimate strength of the sand. The operator records the maximum reading of the gage L.

"The advantage of this strength test are rapidity of test, and simplicity and accuracy of test readings obtained. Strength readings may be obtained at the rate of one a minute with a very small amount of manual effort."

C—Tensile Tests of Green Molding Sands

Because of the low tensile strength of green molding sands it is impossible to employ any of the common tensile tests to make tests of this material. The tensile strength of molding sand ordinarily lies between the values of one-half and five pounds per square inch, depending upon the degree of ramming, amount of moisture in the sand, and its character. The tensile strength is always much lower than the compressive strength.

It is logical to believe that a tensile strength of molding sands is the most indicative test to employ. This is because in testing any molding sand a value is desired which represents the intensity of the cohesion between the sand grains due to the coating of clay or other material which covers them. The tensile test is the only one which measures this directly.

It is conceivable that a mass of compacted sand might have great strength in compression though it did not possess any bond strength at all. To make this more clear consider a mass of

sand made ot square sand grains set closely together as bricks in a wall. The sand would in this case have a compressive strength approaching that of a solid block of silica which is the material of which sand grains are usually composed. The compressive strength would depend very little if at all upon the adhesion between the separate sand grains. With the tensile strength, however, the case would be different, the strength would still depend upon the adhesion between the sand grains. It is of course impossible for any sand mass to be formed of regularly arranged grains of cubical shape, but there is the possibility that a structure might form in a sand mass which would make the compressive strength in a small part independent of the adhesion or bond between the grains while at the same time it is impossible for this to happen in connection with the tensile strength.

The difficulties which stand in the way of a tensile test are more practical than theoretical. There are problems of technique in tensile tests which are difficult to solve and it is difficult to obtain without some care, check tests which satisfactorily agree with one another. The test is very sensitive to disturbing influences.

There have been only two ways suggested for making tensile tests of green molding sands which have come to the attention of the author. One is to make a ring of compacted sand or a nearly square briquette with a hole through the center and insert either of these over some sort of an expanding mechanism which breaks them assunder. The two sides of the briquette or ring are stressed in tension when the specimen is pulled apart. The area which is in tension is the sum of the area of the two branches. By dividing the force used to pull apart the test specimen, which the apparatus employed to break it must be built to measure, by this area the unit tensile strength of the sand is obtained. No details are available of apparatus used for breaking this sort of test specimens. A rubber cell made to fit the opening in the center of the specimen and blown up with air pressure might be used. The air pressure required to break the specimen could be measured and the force upon the specimen which broke it computed. A small hydraulic piston might be employed (in this regard see a note appearing later in this paper

mentioning the Dietert combination apparatus) or some mechanical contrivance might be used.

The second apparatus suggested for making tensile strength tests of green molding sands is the Grubb tension cylinder. This has proved very satisfactory when properly constructed and correctly used and will be described here. The Grubb tension cylinder is not complete in itself but requires some apparatus for breaking the sand specimen. Explanation of how the Grubb

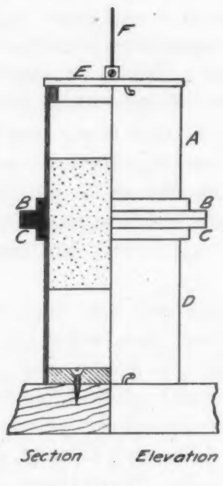

FIG. 15

tension cylinder may be used with other apparatus to pull it apart will follow the description of the cylinder.

(1) *Grubb Tension Cylinder*

The Grubb tension cylinder was designed and first used by A. A. Grubb of the Ohio Brass Company.[14] A drawing of this cylinder is reproduced here as Fig. 15. It is of brass, two

[14] "Molding Sand Reclamation and Control Experiments," Wolf and Grubb, Vol. 32, Pt. 2, Trans. American Foundrymen's Association.

inches in diameter, about five inches long, and with walls $\frac{1}{16}$ inch thick. It is cut crosswise into two parts, one two inches long and the other 3 inches long. The two parts of the cylinder are shown at A and D of Fig. 15. Two brass flanges B and C are soldered to the two adjoining ends of the two parts of the cylinder. By fitting a clamp over these flanges the two parts of the cylinder may be held firmly together. The line of separation of the rings is a sixteenth of an inch higher than the line of division of the cylinder so the two parts of this are held accurately in line.

To prepare a sand specimen the cylinder is clamped together, a steel plug set in the bottom, and moist sand is placed in it and rammed with the A.F.A. permeability rammer. This places the sand specimen in such a position in the cylinder that the middle of it comes even with the line of division of the cylinder.

Following this the cylinder is moved to some apparatus upon which the sand is to be tested. The bottom of the cylinder is provided with a bayonette joint which is used to lock it to the base of the testing apparatus. A cylinder top E is provided which is locked to the top of the cylinder with a bayonette joint. A steel wire or other flexible attachment F runs from the middle of this top to the testing apparatus and serves to apply the force used in breaking the sand specimen. When the sand is ready to test the clamps which hold the two parts of the cylinder together are removed which allows the upper and lower parts of the cylinder to pull freely apart except for the cohesion of the sand. When the pull reaches the required amount the sand specimen is broken apart at the line of separation of the cylinder. After a deduction is made for the weight of the top part of the cylinder, cylinder top, and one-half the weight of the sand specimen, the remainder is the force required to break the sand. To obtain the unit strength the force so obtained is divided by the area of the cylinder.

Usually friction and the tightness of ramming are enough to hold the two ends of the sand specimen firmly in the cylinder, but in the case of some exceptionally strong sands the specimen will slip out without breaking. To prevent this two shallow grooves are turned in the bottom and top parts of the cylinder

about a quarter of an inch back from where the cylinder is split These grip the sand specimen and prevent its being pulled out.

The Grubb tension cylinder has been found very satisfactory when accurately made and used with care. Various ways of locking the top and bottom cylinders have been used and it has been suggested that the bearing faces of the rings be relieved to give bearing at only three points. The design shown here is susceptible of a variety of modifications and the description given is only a simple and suggestive one.

(2) *Apparatus Which May Be Used With the Grubb Tension Cylinder*

(a) Shot and beam apparatus: Referring again to Fig. 7, E is the Grubb tension cylinder in the position it is used with the shot and beam apparatus. The main beam of the apparatus is extended farther to the right than is required for the operation of the compression attachment and a piece of metal G fastened to its end. G is formed in the shape of the arc of a circle with the center of the arc on the line of the knife edge B. This is done to keep the pull on E which is through a wire F extending down from the beam of the apparatus to the top of the cylinder, directly vertical no matter what position beam A may take.

When the cylinder is placed as shown in Fig. 7 and the sand is ready to be tested, locking ring H is removed and the shot is allowed to run into pail M. When this becomes heavy enough the sand specimen will be parted due to the upward tension in F and the flow of shot will be automatically cut off. The shot in pail M is weighed and the stress required to break the sand computed.

It will be found best to make the distance along the beam from the knife edge B to the end of arc G the same as the distance from this knife edge to the knife edge from which pail M hangs. Where the apparatus is used with both the tension and compression attachments, when one is in use a weight must be placed on the apparatus to establish the balance of the beam. Thus when the tension attachment is being used a weight must hang from cord F which is equal to the sum of the weights of

the top part of the tension cylinder, the top of this, and one-half the weight of the tension specimen. It will be convenient to have the beam balance with these in place and pail M removed. This may require that a weight be placed on beam A somewhere on the left side of the main knife edge. By so balancing the beam it will not be necessary to deduct the weight of the pail each time it and the shot are weighed and also it will make unnecessary

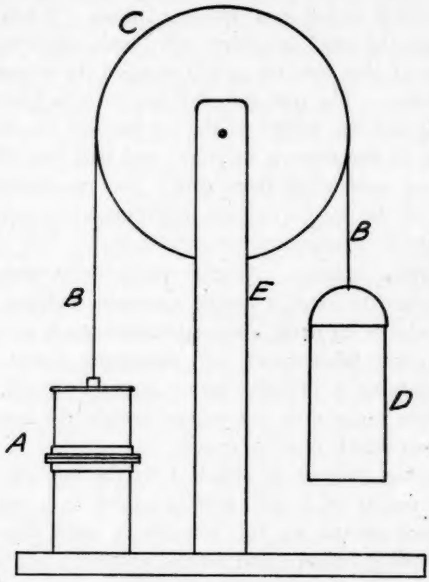

FIG. 16

a correction for the weight of the sand specimen. Separate sand specimens will be found to be uniform enough in weight to make this possible.

(b) Special apparatus: Fig. 16 shows an apparatus* easily constructed by which the Grubb tension cylinder may be successfully operated. At A is a Grubb tension cylinder. This is fastened to a fine steel wire B, which is carried over the grooved

*See further description page 523.

wheel C and fastened to pail D at the other end. C is about eight inches in diameter and is turned from a thin piece of seasoned wood. It is held in a slot cut in the vertical post E, by a small steel pivot about an eighth of an inch in diameter. In addition to the apparatus illustrated in Fig. 16 a weighing scale, supply of shot, and a scoop are required to make tests.

When the tension cylinder is placed in position and the top and bottom unlocked, shot is run into pail D, using the scoop and allowing the shot to fall in a uniform stream. When D becomes heavy enough the sand specimen will break, allowing D to fall. The pouring of shot into the pail is stopped the moment the sand specimen breaks. The pail and shot are then weighed in pounds and decimals and the weight of the top part of the tension cylinder, the top of the tension cylinder, and half the weight of the sand specimen subtracted from this. The remainder is divided by the area of the sand specimen, whereupon the strength of the sand is obtained in pounds per square inch.

(c) Spring balance: Another mannner in which the force may be provided to break a tensile specimen inclosed in a Grubb tension cylinder is by using a spring balance such as is sometimes used in physical laboratories for measuring forces. In using such an apparatus a delicate spring balance should be selected and one whose range does not exceed greatly the strength of the strongest sand which is to be tested.

The spring balance is attached to the top of the tension cylinder by means of a cord and is raised at a uniform speed by some arrangement as, for instance, a cord attached to the top of the spring balance and wound around a shaft which can be turned by a crank. From the time the spring balance begins to place a stress on the sand until the sand breaks, the indicator of the balance is closely watched and the reading taken at the moment the sand breaks. Also the reading of the balance scale after the sand breaks is taken and subtracted from the reading made at the time the sand and specimen broke and result divided by the area of the sand specimen. The result is the strength of the sand in pounds per square inch provided the scale readings are in pounds and decimals and the area is in square inches. (The scale reading after the specimen breaks is the sum of the

weights of the top part of the cylinder, the cylinder top, and half the weight of the sand specimen.)

Spring scales are notoriously inaccurate when not calibrated often, so that if one is used for sand testing this should be done from time to time. It is simple to do this if a few weights are at hand. After considerable use the spring has a tendency to stretch.

It is very desirable to have some means of applying, through the scale, the force to the sand cylinder in steadily increasing increments at a not too great speed. A crank and shaft have been suggested here. It is necessary, also, to have the pull upon the cylinder directed accurately along its axis. Mr. Grubb used a spring scale to operate his cylinder when he first proposed the tensile test. An illustration in the article by Wolf and Grubb previously referred to shows the arrangement he employed.

(d) Moving Weight Apparatus: The moving weight apparatus illustrated by Fig. 10 is fitted with an attachment for operating the Grubb cylinder, but as the attachment is similar in every way to the attachment described for the shot and beam apparatus it needs on further description here.

To use both the tensile and the compression attachments on the moving weight apparatus it is necessary to have either two scales etched on the main beam of the apparatus, one used for tensile tests and the other for compression tests, or to have the distances from the knife edge of the apparatus to where the tension attachment is fastened so proportioned that the scale used for one attachment may be used with the other when a multiplier or divisor is applied to scale readings. When only one scale is used weights must be provided one of which will take the place of the tension cylinder when a compression test is being made and the other which will take the place of the compression cylinder when the tension test is being made. These are required to keep the beam in proper balance.

(e) Moving Fulcrum Apparatus: The attachment shown by Fig. 17 enables the traveling fulcrum apparatus to make tensile tests of green sands when used in connection with the Grubb tension cylinder.

To make tensile tests the compression attachment is removed

from the apparatus and in its place the tension attachment shown in Fig. 17 substituted. The parts of the tension attachment consists of beam U supported by post V which sets upon the end of post F of the main apparatus. A wire extends vertically downward from the left end of U to the middle of the top of the Grubb tension cylinder W. From a point on U at the right of post V a strut X, consisting of a threaded rod with an eye at

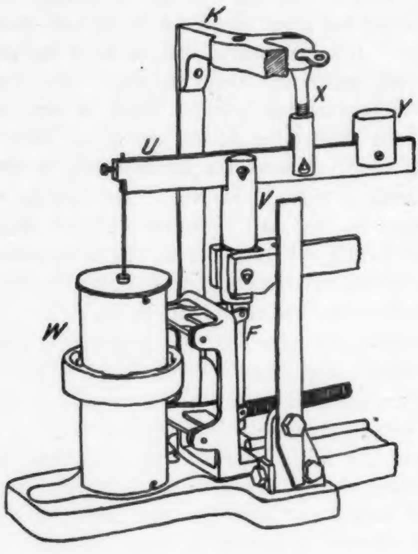

FIG. 17

the top and a forked portion at the bottom, extends upward and is attached to the extension provided on the top bar of the gallows frame. To permit this to be easily removed it is only secured by inserting a pin through the cross piece extension and strut. The end of this pin is shown in Fig. 17. Knife edge bearings are used at the two points where the strut, beam, and post join. U extends farther to the right than the point where strut

X meets it and weight Y, whose use will be explained presently, is fastened upon this.

Sand cylinder W has been provided with a locking ring which does away with all clamps and permits the two parts of the cylinder to be unfastened simultaneously at all points of contact. The construction of strut X which consists of two parts which are screwed together, permits U to be made level at the same time the main beam of the apparatus is level provided the length of the wire is proper. This latter can be adjusted by loosening the screw which secures it to the left end of beam U. These adjustments need be made but once if the apparatus is used on a reasonably level support. The tension cylinder is provided with bayonette joints at the top and bottom. The top joint secures the top of the cylinder to the cylinder and the bottom one is used to fasten the cylinder to the base of the apparatus. A thick circular plate, over which the sand cylinder slips, is fastened to the base of the apparatus and insures that the cylinder is properly centered. The plate forms part of the lock which fastens the cylinder to the base.

In operation, the cylinder with the sand rammed in it is locked to the base and the top is locked to the cylinder. The central locking ring is then turned, which frees the two parts of the cylinder and allows the locking ring to slide down out of the way. The fulcrum is then moved to the left until the sand cylinder separates, indicating that the sand is broken. The scale reading at the moment the sand cylinder separates is three times the tensile strength of the sand and must be divided by three to give the strength in pounds per square inch.

In order to make the best use of the scale of the apparatus and also because sand is weaker in tension than compression, it was necessary to construct the tensile attachment so that the main weight of the apparatus (D in Fig. 12) does not have as great a mechanical advantage when making tension tests as when making compression tests. The attachment has been so designed that a factor of three is used. The distance from strut X to post V is one-half the distance from post V to the wire which descends to the sand cylinder (both measured horizontally along U). This makes the force on the sand in the tension cylinder

increase only one-third as rapidly as the force acting upward at post V.

It is necessary, in order that the scale of the apparatus give true results when different attachments are used, to keep constant the force acting downward on post F of the apparatus due to parts which set on it. This is accomplished in the case of the compression attachment by making the parts of the attachment (including the sand specimen) which are set on top of post F weigh the same. In the case of the tensile attachment it is not possible to make the weight of the parts small enough, so some means must be taken to reduce the force on P. To do this beam U was extended to the left of strut X and sliding weight Y placed on it. This weight counterbalances part of the weight of the sand cylinder when the attachment is under stress (at other times it causes a slight initial force on the apparatus which is beneficial in raising the top of the sand cylinder up and allowing the cylinder to be placed in position without interference) and is set so that the total force downward upon post F due to the weight of the parts of the attachment is the same as in the case of the other attachments for which the scale of the apparatus is calibrated. When the position of Y is once determined it is permanently fastened there. It might appear that the difference in weight of individual sand specimens might cause some inaccuracy in the operation of the apparatus. However, this difference in weight, though it exists, is so small that it may be neglected in the calibration of this apparatus. (The error introduced is a small fraction of one per cent.)

D—Transverse Test of Green Molding Sands

A transverse test is a test made by bending a bar of material and determining what force is required to break it. The greatest stress at the breaking point can be calculated from the unsupported length of the bar, the dimensions of the bar, and the force which causes the bending. It is also true that if the dimensions and unsupported length of the bar are kept constant the force required to break the bar is a measure of the strength of the material of which it is formed.

In bending there is always one section across the bar where

the stress is greater than at any other. This is called the critical section. Also in this section, which cuts across the bar, the stress varies from zero somewhere near the middle of the bar (at the middle if the material is truly elastic) to maximum compression at one surface of the bar and maximum tension at the opposite surface. If the bar is supported on two bearings, one at each end, and a weight is hung from the middle of it, maximum compressive stress will occur at the top of the bar at the middle, maximum tensile stress will occur at the bottom of the bar at the middle, and a section cutting through the middle of the bar will be the critical section. If a bar overhangs the edge of a table, maximum tensile stress will occur at the top of the bar just above the edge of the table, maximum compressive stress will occur at the bottom of the bar at the edge of the table, and a section cutting through the bar even with the edge of the table will be the critical section. Whenever the stress at any point in the bar exceeds the strength of the material the bar will break. If the material is uniform throughout, the stress will first reach the breaking point at the critical section and in the case of sand which is weaker in tension than compression, breaking will start at the point where the maximum tensile stress exists. The breaking stress calculated from a transverse test should be the same as that determined by a direct tensile test and would be if the sand is the same kind, has the same water content, has been compacted to the same degree, and a correct method of calculating the stress is used. Some difficulty is introduced in obtaining the same compaction in differently shaped sand specimens and in developing a truly accurate method of calculating the stress which exists in the bar due to a certain loading. Discrepancies between tensile tests and transverse tests which some investigators report are attributable to these facts.

As has been intimated, a bar of green sand might be tested by applying a measured load to the center. This, however, is not satisfactory and another means has been adopted.

(1) *Transverse Test Apparatus Sponsored by the American Foundrymen's Association*

The first test adopted by the American Foundrymen's Asso-

ciation was a transverse test suitable for any green sand such as molding sand or a steel sand before it is baked. The principle of this test is to push a bar of sand over the edge of a plate and allow it to break to the weight of the overhanging piece. The stronger the sand the greater the weight of the overhanging piece which breaks off, so this may be caught, weighed, and its weight taken to represent the strength of the sand. This test has been used to a limited extent for some time in a crude form.[15] R. J. Doty of the Sivyer Steel Casting Co., of Milwaukee, acting with the American Foundrymen's Association, is principally responsible for developing the test to its present stage of refinement and for its adoption by the Sub-Committee on Standard Tests of the American Foundrymen's Association. Since its adoption by the A. F. A. it has received wide publicity and has been used to a considerable extent.

Instead of giving a complete description of the test in this paper, a thing which is unnecessary in view of the complete description and instructions for carrying on the test given in the Trans. of the Am. Foundrymen's Association,[16] only the essentials will be noted and some comment upon the test offered. For a more detailed description the reader is requested to consult the references given.

Great care is taken in preparing the test bar in order to obtain one of uniform consistency, size, and compaction. A mold is employed whose sides may be removed without any great jarring of the sand bar and permitting the base of the mold to be used in the pulling machine. This makes it unnecessary to handle directly the bar in any way.

The sand is riddled into the mold with a special riddle which distributes the sand well in the mold, though this is subsequently perfected by using strikes to level off the surface of the sand, and prevents any large lumps from becoming part of the bar. Several strikes of different depth are provided which are guided by the top of the mold and which thus level the loose sand very evenly.

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[15] Alexander E. Outerbridge, The Improvement of Molding Sand by Mechanical Treatment, Trans. American Society of Mechanical Engineers, Vol. 29, 1907, Page 868.

[16] Tentatively Adopted Methods of Tests, Trans. American Foundrymen's Association, June, 1924.

The sand is rammed with a drop-weight rammer. The weight, distance it drops, and the number of drops are specified so that the compaction is kept constant. To this same end the thickness of the finished bar is specified within narrow tolerances.

It was found when tests were made that the rate at which the bar was pulled over the end of the plate when it was broken influenced, with some sands, the strength result obtained in the test. To obtain a constant rate of pulling a device operated by an electric motor was devised. Before the sand is riddled into the mold a strip of waxed paper is placed on the bottom with enough surplus length at one end so that when the bar is ready to be pulled this end can be threaded into a slot on the shaft of the motor pulling device. The shaft is rotated at a low rate of speed through a train of gears by the motor. As the bar is pulled over the edge of the plate pieces drop off and are caught and separately weighed. The average of their weight expresses the strength of the sand. It would be possible, knowing the weight of the sand which went to make the bar, to calculate the breaking strength in pounds per square inch. For making such calculations where tests are made without obtaining the weight of sand in the bar an average weight may be assumed and the calculations based upon this with fair accuracy.

(2) *Modified Bar Test*

Notwithstanding the high degree of refinement in the apparatus adopted by the Sub-Committee on Standard Tests of the American Foundrymen's Association for conducting the transverse test of green sands, a considerable length of time is required to conduct a single test and there are some undesirable features in carrying it out. One of these is that as the sand is riddled into the bar mold there is a tendency for the larger particles of a coarse sand and small lumps of any sand which is tempered with difficulty, to pass through the riddle last and form predominantly the top part of the bar. As the bar is broken in the same position it is formed, the coarse particles on top which do not cohere as strongly as the remaining part of the sand are a source of weakness. Further, the apparatus required to make the bar test is expensive.

The author suggests the apparatus shown in Fig. 18 for making transverse tests of molding sands. This apparatus has features which decrease greatly the time required to make a test and in its design an attempt has been made to eliminate some of the undesirable features introduced by the apparatus at present employed for making transverse tests of green sands. By making the apparatus one single unit instead of several detached pieces, there is a great reduction in complication when the whole of the several pieces of apparatus is compared with the simple unit apparatus. Making the apparatus compact and somewhat smaller has been the means employed to decrease the number of movements and the labor of making a test and makes it possible to perform the test in a fraction of the time formerly required.

As shown by Fig. 18 all of the apparatus is placed on a cast iron base A. The same divisions occur in this apparatus as with the apparatus used at present, including the pulling device, mold, riddle and ramming device.

The mold is formed by a base B, end pieces C and D, back E, and front F. It is fastened by means of its base to cast iron base A so that it cannot be removed but can be swung upon pivots G and H up and forward. The back of the mold is fixed to the base of the mold and the end pieces are pivoted to the back. The pivots upon which the ends swing are arranged so that when wheel I, which forms part of a closing mechanism for the end plates, is turned in a clockwise direction the ends of the mold swing outward. They are provided with parts on the front which overlap the front of the mold. This front is loose and the overhanging portions of the ends serve to hold it in position. Wheel I both closes and opens the end pieces and serves to lock them in their closed position. This mold is intended to make a bar one inch wide, twelve inches long, and one inch high.

Sand is screened into the mold through riddle J, which is supported and may slide from side to side on frame K. This frame can be slid from back to front upon rail L and one like L in a corresponding position on the other side of base A. A stop is provided for frame K, so that when it is pulled forward the bottom opening of the riddle registers with the opening in the

top of the mold. A mechanism consisting of a shaft with a crank at one end and carrying a ratchet wheel at its center, a spring, and a rod fastened at one end to the riddle and with the other bearing

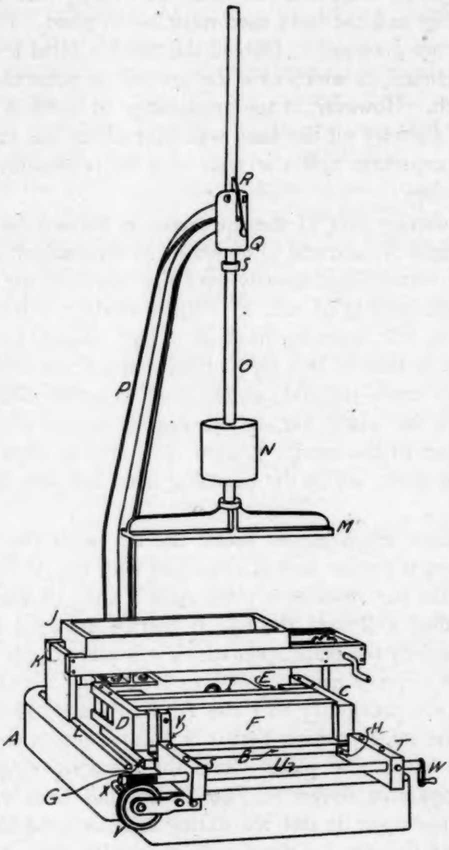

FIG. 18

against the perifery of the ratchet wheel, is shown at the right end of riddle frame K and serves to vibrate the riddle to aid in evenly distributing the sand in the mold.

A single, adjustable strike is furnished with the apparatus which may be set for any depth and is used to level off the top of the sand in the mold before it is rammed.

For accurate tests the bar must be exactly one inch thick after ramming and the sand used must be weighed. For control tests this is not necessary. Instead the mold is filled level full of sand and rammed, in which case the bar will be somewhat thicker than one inch. However, if too great range of sands is not being used in the foundry all the bars will have about the same thickness and compaction and the tests will be reasonably accurate and comparable.

The ramming part of the apparatus is formed by ramming head M, weight N, and rod O to which M is attached. The axis of rod O is vertical and directly over the center of the mold. It slides through head Q of arm P. When not in use for ramming it is raised so that ramming head M is high enough to be out of the way and is held in this position by catch R on head Q. By releasing this catch the rod, weight, and ramming head may be lowered until M, which fits the opening in the top of the mold, rests upon top of the sand. Weight N is free to slide upon rod O within the limits set by the ramming head and stop S fastened to rod O.

The means employed to break the bar with the apparatus described here is similar to that employed with the A. F. A. apparatus; viz., the bar rests on a plate upon a strip of waxed paper which is pulled and thus the bar is carried forward and overhangs the edge of the plate upon which it is placed until the overhanging part becomes heavy enough to break off. An explanation has been made previously that the A. F. A. method of pulling the bar in the same position that it is formed places the weakest part of the bar at the place where the breaking stress occurs. With the apparatus shown in Fig. 18 this has been avoided by turning the bar upon its side for testing and the mold has been so arranged that this can be done without handling the bar, which would be impossible with weak sands.

In turning the bar on its side any stratification which may exist due to distribution of the coarser particles or to uneven ramming is made vertical and in this position does not weaken

the bar to the same degree as though it were horizontal. A complete explanation of this requires a discussion of the theory of flexure, but to go into this would demand so much space as to be out of place at this point.

Another advantage of turning the bar on its side is that a constant height of bar is assured and it is true that a small error in height introduces a much greater error in strength than a small error in width. It is this fact that makes it possible to allow an appreciable departure from 1 inch height measured in the ramming position and where the test is a control test.

After the bar is prepared the mold is swung upward and forward upon the pivots G and H, which brings the front of the mold in place upon the two rests S and T. While the mold is in this position the ends of the mold are swung outward by turning wheel I and the mold then allowed to swing back into its former position. This leaves the bar ready to be pulled over the edge of the front plate of the mold which is now under it. In preparing the sand bar, before the mold is filled with sand a strip of paper is placed alongside F of the mold and when the bar is in position to be pulled this is under it. A generous overhang is allowed on the right hand end of this paper strip which enables it to be threaded into the pulling device.

The pulling device consists of shafts U and X and gear V, which engages with a worm at the end of shaft U. The other end of shaft U is provided with a crank and handle W so that U may be turned. Gear V is fastened on shaft X and this latter has a slot in it through which the end of the paper upon which the sand bar rests can be threaded. By turning crank W the sand bar is drawn to the left. A lug Y is fastened to the front plate of the mold and serves to prevent this from moving forward as the bar is pulled, by coming to a stop against rest S.

It was felt in designing this apparatus that a motor on the pulling device was unnecessary because anyone will in all cases turn a crank within comparatively narrow limits of speed. It is very difficult to turn a crank faster than five turns per second and very trying to one's patience to turn a small crank such as is used on this apparatus slower than about one turn per second. One would normally turn such a crank between the narrow limits of

two and three turns per second. The speed of this apparatus has been so set, by proportioning the gearing, that when the crank is turned at 2.5 turns per second the rate of movement of the bar is the same as that of the A. F. A. bar with its motor pulling device.

The portions of the bar as they fall off, slide down the waxed paper into a pan. Instead of weighing these the turning of the handle W is stopped the instant a piece breaks from the bar and with a scale provided with the instrument the forward advance of the bar since the last piece broke off is measured. This scale is calibrated in pounds per square inch breaking stress and makes the correction necessary for difference in weight of sand which goes to make up bars of one inch height when sands of different densities are tested. This is probably a more accurate means of determining the strength of the sand, than weighing the several parts that break from the bar. It will sometimes happen that the bar will break a little back or a little forward of the edge of the plate where the maximum stress occurs. The weight of the broken portion will, therefore, be a little heavier or lighter than it should be and if the stress is based upon this, as it is when the pieces are weighed, somewhat erroneous results will be obtained. In addition, the scale saves considerable time and saves handling the sand after it has been broken. The sand may be allowed to drop directly into a waste can.

To operate this apparatus a strip of waxed paper is placed on the inside of the front of the mold with enough extra to bring around outside of the mold so that the paper can be held tight while the front piece is being placed in position and the ends of the mold closed tightly upon it. The riddle is then drawn forward and filled with a weighed amount of tempered sand which is riddled into the mold. The sand is then struck off, if for an approximate test, even with the top of the mold, if for an exact test, at a height (using the strike) which will when rammed make a bar one inch high. Catch R is released and the ramming head is lowered (slowly by hand) into the mold and allowed to rest on the sand. The weight is then raised until it touches the top stop and is allowed to fall.[17]

[17] The heaviness of this weight and the number of times it is dropped may be set so that the same compaction is produced in the sand as is produced in the A. F. A. bar.

Where the test is an approximate one no further preparation of the bar is required, but if the test is an exact one the apparatus must be observed to see whether the bar, after ramming, is of the proper height. This is indicated by a mark on rod O which is at the same elevation as a mark on a scale attached to the head Q of arm P when the bar is one inch in thickness. The marks for the allowed tolerance are also placed on this scale which resembles in its arrangement and operation the scale used on the A. F. A. permeability rammer. If the height of the bar is not within the allowed tolerance it must be discarded, a new amount of weighed sand taken, and a new bar made.

The ramming head is raised after a satisfactory bar has been rammed until catch R again engages the rod and holds it up and the mold is swung upon the rests S and T. After the ends of the mold have been swung out releasing the front of the mold and sand bar the mold is swung back and the end of the waxed paper is threaded into the slot of shaft X of the pulling device. Handle W is then turned in a clockwise direction at a steady speed until a portion of the bar breaks off, at which instant turning is stopped. The advance of the bar is then measured with a scale provided with the apparatus and the strength of the sand obtained. Several breaks may be obtained from one bar and a corresponding number of strength determinations made. The true strength is taken as the average of these.

The scale used provides for a setting before the pulling of the bar is started and at the position of the bar after each portion has broken off which enables the direct measuring of the length of the broken pieces using the strength calibrations of the scale. The scale is so calibrated that there is provision on it for making correction when sands of different densities are tested so that the true strength of the bar may be obtained. These corrections need only be made when exact tests are being carried on.

The weight of sand required to make a bar of one inch thickness is directly proportional to the density of the compacted sand and is used in connected with the scale for making the correction. The scale is direct reading, no calculations are necessary.

The A. F. A. bar test makes no correction for difference in density and in neglecting to do this introduces a small error in

the test. Compacted sands having relative densities of trom 79 to 100 percent are encountered and as the error in comparing the strength of these sands is in direct proportion to the density, one sand might have exactly the same strength as the other yet because of its difference in density be shown by a pulled-bar transverse test making no correction for density, to be as much as 21 percent stronger than the other.

E—Apparatus for Making Tests of Baked Sands

The strength range of baked core sands and dried sands is so much above that of green molding sands and steel sands that it is inadvisable to use the same apparatus for making tests of both without some alteration in the apparatus. For instance, before a baked oil-bound core sand bar would break by being pushed over the edge of a plate the length would become so great that very unwieldly apparatus would be required to make the test. The apparatus, descriptions of which follow, will be found satisfactory for making tests of all foundry sands that are strongly bonded due to the addition of some strong artificial bonding material and baking. It is possible that weaker sands belonging to this class, sands which are bonded only with clay, may after baking be so weak that they will come in the strength range of molding sands. Hereafter in this paper oil-bound core sands, dried sands, and similarly bonded sands will be referred to as baked sands.

(1) *Compressive Tests of Baked Sands*

Compressive strength of baked sands lies much above the tensile strength. It also lies well above the strength capacity of small apparatus such as are used in testing green molding sands, so, to make compressive strength tests of specimens of baked sands some form of standard testing machine is recommended.

Baked sand compression specimens are ordinarily prepared in the same way as compression specimens of green sands. The loose, tempered sand is placed in a cylinder and rammed with the permeability rammer (or some other one) and the compacted specimen pushed out of the cylinder. Following this the specimen

may be baked in any manner desired. Instead of ramming oil-bound core sands it may be desired to compact them by vibrating, in which case a vibrating apparatus which will be described later may be used. A split mold must be used when sands are compacted by vibrating for the sand is too weak to be pushed from a cylinder made in one piece.

Several types of testing apparatus are on the market which may be used for making compression tests of dried sands. One having a useful range of from five hundred to four or five thousand pounds should be used. As these testing machines are expensive, it will not be possible for the ordinary sand laboratory to equip itself with one for the purpose of making sand tests alone. If but a few tests are to be conducted the specimens may best be taken to an established testing laboratory which has a machine available.

Compression tests of baked sands may be supplanted by tensile or transverse tests for control work and by so doing avoid the outlay necessary for an expensive testing machine.

An apparatus for making tests of green sands similar to the one shown in Fig. 8 might be made of steel instead of wood, furnished with a large supply of shot, and used for making tests of baked sand compressive specimens. The lever ratio must be increased by placing the sand specimen near the pivot and making the beam long.

(2) *Tensile Tests of Baked Sands*

The only tensile test which has been used for baked sands is one which follows very closely the briquette test used in making tests of cement and cement mortars. The test involves preparing a briquette of special shape and pulling it apart in a special machine. The strength range of baked sands falls within the useful range of apparatus at present on the market for making tests of cement and therefore any of these may be used for making tests of baked sands. An attachment has been devised for the moving fulcrum apparatus which permits of making tensile tests of baked sands; this will be described after the means used to prepare a sand briquette are explained.

(a) Preparation of Sand Briquettes: Sand specimens for testing of sands which are to be used for dry sand molds are compacted by ramming. Also, some may desire to compact oil-bound core sand specimens in this manner though it is more common to compact these sands by vibrating.

To prepare a briquette specimen the mold and ramming head

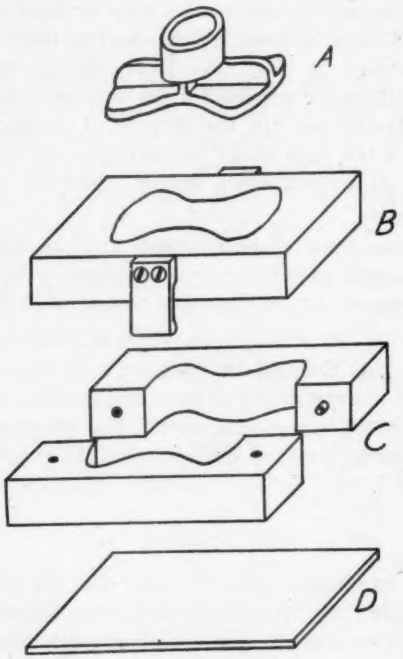

FIG. 19

shown by Fig. 19 may be used in connection with a light rammer such as the A. F. A. permeability rammer. The mold complete consists of three parts B, C, and D (Fig. 19). D is the base, C is the mold box proper, and B is termed the surplus frame. The mold proper is built so that it separates into two parts as

shown. Dowels and holes are provided to retain the two pieces of the mold in their proper relation when they are put together.

The surplus frame B is made in the same form as the mold. It is, however, not divided into two parts. The opening in it exactly registers with the opening in the mold when they are brought together. Dowels in the under side of the surplus frame and holes in the top of the mold insure that the surplus frame is brought into the correct position when placed on top of the mold. On each side of the surplus frame is a finger which extends below it and pushes against the side of the mold box with considerable spring pressure. These two fingers clamp the mold tightly together.

For the preparation of a sand bar the mold with the surplus frame in position on top of it is placed on base D, which is simply a flat plate of steel. Prepared sand is riddled into the

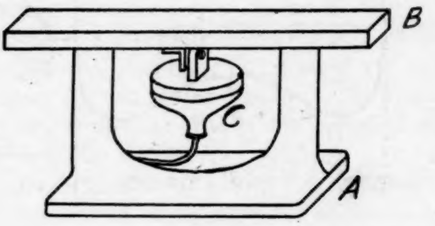

FIG. 20

assembled mold and ramming head A placed on top of it. Ramming head A is formed so that it fits closely the opening in the surplus frame and the mold. It also has a circular recess on top into which the end of the rammer fits. To ram the sand, the mold and ramming head are placed under the rammer and the end of this is fitted into the ramming head. The weight of the rammer is then raised and allowed to drop some agreed-upon number of times, after which the mold is removed from the rammer, the ramming head and surplus frame lifted off, and the mold separated. This leaves the briquette upon base D. The briquette may be transferred to the oven and baked upon the base, which will

avoid handling the briquette with the hands or with tongs while in its green, soft condition. The base of the mold is simply a section of rolled steel plate and it is no burden to supply a large number so that many briquettes may be baked at once.

(b) Vibrating Core Sands: By some it is considered essential that core sands be compacted for testing by vibrating them rather than compacting them under the blow of a rammer. An apparatus for doing this is illustrated by Fig. 20.

The apparatus consists of a heavy cast iron base A upon which a heavy iron bar B sets. This is loose from base A, but is prevented from sliding off the top by two loose dowels which

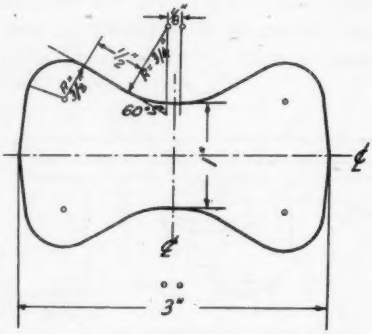

FIG. 21

extend up into it from the base. An electric vibrator is attached to the underside of bar B as shown at C.

To use this vibrating apparatus in connection with the briquette mold shown in Fig. 19 the assembled mold together with its base is set on top of bar B of the vibrating apparatus. The mold and surplus frame are filled with the core mixture and while the mold is held lightly in position with one hand the vibrator is started and allowed to run some definite length of time. After this the surplus frame is removed and the excess sand struck off level with the top of the mold. The mold is then carefully pulled apart, leaving the briquette setting on the base upon which it may

be removed to the oven and baked. Should this method of preparing the briquette become generally used it would be desirable to standardize it. To do this it would be necessary to specify the weight and dimensions of the briquette mold and of the vibrating apparatus and also specify what vibrator is to be used, how it shall be placed and how long it should be operated to give the proper compaction. In addition, the time the briquette should be baked and the baking temperature must be specified.

The same form of briquette may be used for tests of baked sands as is used for cement tests. However, one which is better adapted for sands is shown by Fig. 21. The form of this one is sufficiently close to the cement briquette that either may be used with the clips supplied with briquette testing machines.

The plan of using a surplus frame with a mold that may be separated was first proposed by H. W. Dietert in connection with a mold used to form the test specimen for a transverse test of baked sands. The mold used by Dietert is very similar to the one which will be described later in this paper. Also Dietert proposed the means employed for vibrating core sands.

(c) Tensile Briquette Test Attachment for Moving Fulcrum Apparatus: An attachment devised for the moving fulcrum apparatus enables it to make tensile tests of baked sands. This attachment is shown by Fig. 22.

The attachment consists of a beam AA supported on one end by a post BB which is set on top of post F of the moving fulcrum apparatus. The other end of AA rests on post CC, which is screwed into the base of the apparatus near the left end. One briquette clip is suspended from a knife edge on AA, while the other one is below it and is fastened to the base of the apparatus by means of a screw. The screw enables the height of the lower clip to be regulated and provides a swivel joint which enables the lower clip to adjust itself to an even straight pull on the briquette. This same result is accomplished in the case of the upper briquette clip by the suspension shown. A weight DD rides on beam AA. Other attachments are of course removed from the apparatus when this one is used.

To operate the briquette tension attachment the briquette is placed in position in the clips as shown by Fig. 22 and the screw

which secures the lower clip to the base turned, thus drawing the clip and briquette down until beam A of the apparatus is level. (This is indicated by the level vial attached to beam A. Beam A is the main beam of the apparatus; only the end of it is shown in Fig. 22.) The fulcrum carriage is then moved to the left until the briquette breaks. The scale reading at the moment it breaks

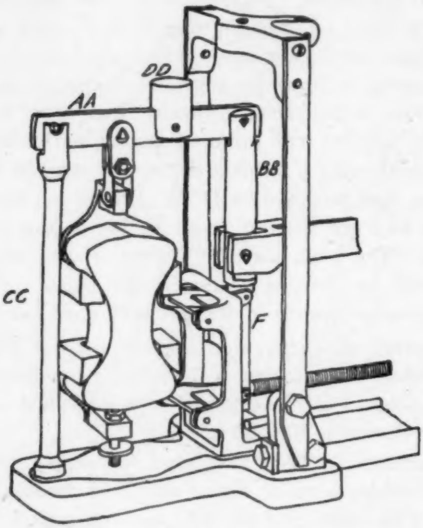

FIG. 22

is one-tenth its tensile strength, so to obtain the tensile strength in pounds per square inch this scale reading is divided by ten. The use of this easily handled factor is made possible by the setting of the distance from the point of suspension of the briquette to posts CC and BB. (Distances are measured along AA.) Weight DD serves the same purpose in the case of this attachment as weight Y did in connection with the attachment used with the Grubb tension cylinder, with the exception that in the case now under consideration the downward force upon post F of the apparatus is too light and DD serves to increase it rather than

decrease it, as was the case with the other attachment. When the position of DD is ascertained so that the constant force downward upon F is equal to that in the case of the other attachments used with the moving fulcrum apparatus it is permanently fastened in place.

(d) Wadsworth Core Sand Testing Apparatus: A briquette testing apparatus has been placed on the market by the Wadsworth Core Machine and Equipment Co. It is quite simple in operation and consists of two briquette clips which hold the two ends of the briquette. One of the clips hangs down from the frame of the apparatus. The other clip is attached to a lever which serves to apply the force to pull the briquette apart. A pail hangs from one end of the lever and shot is allowed to run from a shot supply bin into the pail. As the pail increases in weight the force on the briquette becomes greater until the briquette finally breaks. When this takes place the shot supply is shut off and the pail with the contained shot is weighed and the force on the briquette calculated.

(e) Cement Briquette Testing Apparatus: Several types of cement briquette testing apparatus are on the market. They are common equipment in cement testing laboratories and need not be described here.

(f) Transverse Tests of Baked Sands: The transverse test is a very convenient one to make on baked sands. These sands are high enough in strength so that they may be made into bars which may be supported on two supports near the ends and loaded at the middle until they break. By employing this test the high stresses which are encountered in the compressive test of baked sands are avoided and in addition the difficulties of technique which are faced in the briquette test may be avoided. Most of the tests which have been made upon baked sands have been transverse tests. Anticipating the wider adoption of this test some steps should be taken to standardize it. For this purpose the size of the bar used and the manner in which it is rammed, as well as the length of time it is baked and the temperature of baking should be specified. It is of no concern upon what apparatus the bar is broken as long as the distance between supports is the same; this distance should be specified.

The test specimen for the transverse test is a bar of moderate length. A bar made in the A. F. A. transverse test of green sands apparatus, baked and separated into halves has been used for a transverse test of baked sands specimen. Each half of the bar forms one specimen so that two tests may be made with one molded bar. It is probably better to employ a bar of different dimensions for the baked sand test than the one made by the A. F. A. green sand transverse test apparatus and the dimensions agreed upon should be set up as a standard. As will be explained later, a great speed of testing may be obtained for control tests by using apparatus which are built to indicate directly the strength of the bar after testing. This requires that in all cases the bar have the agreed-upon standard dimensions.

A mold for preparing transverse specimens is shown by Fig. 23. The arrangement of this mold is the same as that previously described for preparing briquettes. The same parts are provided, viz., the ramming head, the surplus frame, mold proper, and base. The mold is built of mild steel bar about 15/16 or ⅞ of an inch thick and as wide as it is desired that the height of the bar shall be, usually one inch. The mold proper divides into two parts, each one of which consists of an end and a side. Dowels are provided to hold the pieces of the mold in proper relation and to hold the surplus frame in the proper position when it is placed upon top of the mold.

When using this mold to prepare the sand test bar the sand may either be rammed, using the ramming head provided with the mold and the A. F. A. permeability rammer or it may be compacted by vibrating with the apparatus shown in Fig. 20. Likewise, after the bar is rammed and the mold removed the bar may be taken to the oven for baking upon the base of the mold.

Several apparatus may be used to break the bar after it is prepared. Mr. Dietert, who devised the hydraulic compression testing apparatus described under the compression test of molding sands, has devised an attachment which enables this apparatus to make transverse tests of baked sands. The attachment consists of bar of iron which takes the place of the fixed plate against which the compression cylinder bears. The iron bar has two supports, one at either end, upon which the test bar is placed.

Also it has at either end a projecting bearing which allows the test bar to be in contact with it only at these two points. The piston of the apparatus bears against the center of the bar and as it is forced out bends the bar until it breaks. The length of the bar is so proportioned that the gage of the apparatus indicates the stress which was required to break the bar, in pounds per square inch.

It is possible to adapt an apparatus such as the one shown in Fig. 8 to the making of cross breaking tests of baked sands if two bearings are provided upon which the bar may lay and one is provided to place on top of the bar at the middle against which the beam of the apparatus may rest.

(g) Transverse Test Attachment for the Traveling Fulcrum Apparatus: An attachment shown by Fig. 24 has been provided for the traveling fulcrum apparatus which enables it to make transverse tests of baked sands. To place this attachment in operation pan 1, the base H, and screw L carrying plate J (Fig. 12) are removed from the apparatus and replaced by screw Q, post R, and attached parts (Fig. 24). A long steel bar S is fastened on top of post R and it is upon this that the sand specimen, which is a bar, sets. Two cross bearings are provided at each end of bar S, which raise the sand specimen above the bar and permit a downward force from a similarly formed bearing attached to the lower end of the screw Q to bend the sand specimen. The cross sections of the three bearings which come in contact with the sand specimen are made semi-circular so that they will not dig into the sand when it is stressed. Fig. 24 does not show the remainder of the traveling fulcrum apparatus which operates in connection with the transverse test attachment exactly the same as with the compression attachment.

The operation of the apparatus when performing a cross breaking test is as follows: As the fulcrum is moved toward the end of the beam which presses upward on post F the sand sample is pressed upward with a force which increases as the fulcrum is moved. When this force becomes great enough the sand sample breaks and the motion of the fulcrum is stopped at the same instant. The scale is read and its reading multiplied by 30 to give the strength of the sand in pounds per square inch. As sand is

in all cases weaker in tension than compression the sand will first break at the point at maximum tensile stress and the strength obtained is the tensile strength of the bar. The bar used is one inch square and the distance between the supports upon which it is broken is six and a fraction inches. The distance between supports is made such that the factor 30 may be applied to the scale reading to give the true stress in the bar at the time of breaking.

The weight of the sand bar used in the test and the weights of the parts S and R of the attachment must, when added to-

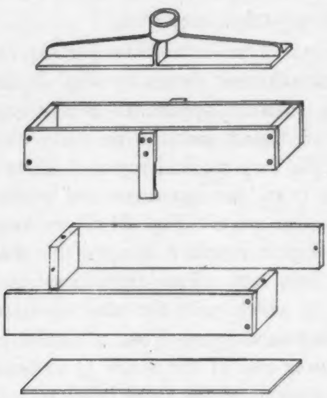

FIG. 23

gether, equal the weight of the sand cylinder used in the compression test plus the weight of the pan I and base A (Fig. 12). Bearing T is attached to the lower end of screw Q by means of a swivel joint so that in turning screw Q down on the sand bar, T need not turn and will be brought to an even bearing on the top of the bar.

F—Miscellaneous Tests

(1) *Dietert Combination Apparatus*

As none of the details are available of an apparatus developed by H. W. Dietert, for making all of the tests possible upon mold-

ing sands and core sands, the description of this apparatus has not been placed in its proper place with the description of other apparatus in this paper. The Dietert combination apparatus makes provision for conducting compressive, transverse, tensile and shearing tests of molding or other low strength sands and also the same number of tests of baked core and other high strength sands.

The essential parts of the apparatus are a small hydraulic piston and cylinder, a force pump, and pressure gages. A large range of pressures must be measured so that two gages are provided, a mercury manometer for the lower pressures and an ordinary dial gage for the higher pressures.

The compression test is made with a cylindrical specimen which is crushed between the head of the hydraulic piston and a stop. The cross breaking test is made with a small bar specimen which is broken by bending between a bearing carried on the piston and two bearings which the bar sets. The tension test is made with a hollow square specimen which is pulled apart by being slipped over the piston and cylinder. The piston pushes outward against one side, while the other is held by the base of the piston. The shearing test is made by compacting the sand in a cylinder which has another cylinder at right angles to the first and sliding through it. The sand is sheared by pushing the second cylinder out of the first.

Specimens are prepared in special molds in a similar manner to that used to prepare any of the specimens described in this paper.

(2) *Ball Hardness Test*

The comparative hardness of compacted sand may be determined by dropping a small steel ball about three-eighths of an inch in diameter from a height of about ten or twelve inches upon a flat surface of the sand. The diameter of the indentation made by the ball is measured and this taken as an index of the hardness. In using this test the ball must be dropped free, no guide should be used, and the surface of the sand should be level and very smooth. It will be valuable to powder a little ground chalk or talc over the surface upon which the indentation is made before the ball is dropped. This will aid in delineating the boundary

of the indentation and makes a more accurate measure of the diameter possible. The diameter of the indentation may be measured with a steel scale calibrated to hundredths of an inch.

Instead of dropping a ball upon the sand a small instrument described by E. Ronceray[18] may be employed. This consists of a hollow cylinder having an internal diameter of about 3/8 of an inch. The cylinder is three or four inches long and has at one

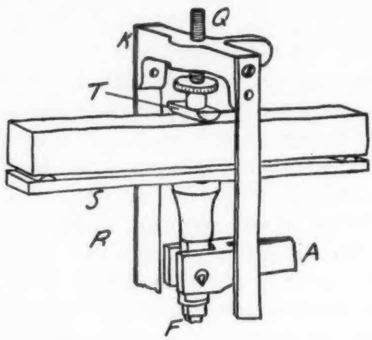

FIG. 24

end an outside flange and a small inside ring which serves to retain a loosely fitting steel ball in the tube. The ring is made small enough so that the ball may project nearly one-half its diameter beyond the end of the tube and the face of the flange which is flush with the end of the tube. A cap is placed on the other end of the tube and between this and the ball is a spring which is compressed to a certain tension and tends to force the ball from the tube. To operate this apparatus the ball is pushed against the smooth surface of the mold upon which a little powdered chalk or talc has been dusted until the flange rests on the sand. The apparatus is removed and the diameter of the indentation measured. This is taken as an index of the hardness of the sand.

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[18] A new method for measuring the hardness of molds—E. Ronceray, Trans. American Foundrymen's Association, Vol. 32, Pt. 2, Page 17.

The spring arrangement has the advantage over dropping the ball in the fact that it may be used upon surfaces which are not horizontal.

Either of these hardness tests are empirical and they may or may not bear any direct or ascertainable relation to the strength of the sand. They are valuable in dealing with one kind of sand, as for instance, when it is wished to keep a continuous control upon the amount of ramming which is given to molds in the foundry. The test was probably suggested by the Brinell test for the hardness of metals.

SUPPLEMENT

Since the foregoing paper was written there has been some development of foundry sand strength testing equipment not recorded therein and because of the new features possessed by newly proposed apparatus it is desirable to add to the descriptions of apparatus appearing in the second part of the paper. The great rapidity with which the testing of molding sand is being adopted by the foundry industry and the consequent rapid developments of testing methods and technique make it very difficult to record all the ramifications in the design of testing apparatus that it would be desirable to do.

Saeger Spring Compression Apparatus

An apparatus illustrated by Fig. 25 has recently been devised by C. M. Saeger, Jr., physicist, U. S. Bureau of Standards for making compressive tests of green molding sands. The specimen employed is the same as that used in the A. F. A. permeability test, namely, a 2-inch by 2-inch cylinder, but the rammer suggested by Mr. Saeger for preparing the specimen differs in some respects from the standard A. F. A. rammer.

The rammer and other apparatus for testing the specimen are shown by Fig. 25. The apparatus for preparing the specimen consists of the four pieces shown at the left while the testing apparatus proper is at the right in this figure.

The pieces of apparatus used in preparing the sand specimen named in order from left to right as they appear in Fig. 25 are:

sand cylinder, base, rammer, and pushing out block. In preparing a specimen the procedure is the same using this apparatus as with the A. F. A. standard rammer excepting that the rod, weight, and ramming head which form what has been here called the rammer are free, not being held in a frame with guides as is the case with the A. F. A. rammer, thus making it necessary to steady the rod of the rammer by means of the handle at the upper end while the sand is rammed. The tolerance marks are placed on the side of the rammer head instead of on a special scale. The rammer head is necessarily long, for it must be largely depended on to guide itself. By making the weight of all parts which bear on the

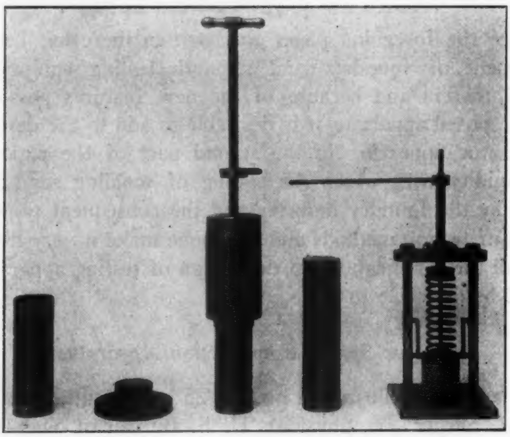

FIG. 25—SAEGER COMPRESSION APPARATUS

sand exactly the same in this rammer as the corresponding parts in the A. F. A. standard rammer the degree of ramming for specimens prepared on either apparatus is the same.

The compression test apparatus shown at the right in Fig. 25 is constructed as follows: Two substantial steel rods extend upward from a square steel base and carry at their upper end a horizontal steel cross bar having a vertical threaded hole in the center. A rod about ½-inch in diameter and 5 inches long and having a long handle at its upper end threads through this hole and is fastened at the lower end through a suitable swivel connec-

tion to the top end of a coiled compression spring. The lower end of the spring carries a horizontal plate which is guided in its vertical motion by guides sliding loosely on the main rods of the machine. The swivel joint between the threaded rod and the spring has a ballbearing thrust bearing, so motion there takes place with little friction.

The threaded rod is hollow along its axis and a loose calibrated rod slides loosely through its center. Sufficient friction is afforded to hold this rod in any position it may be placed by a spring finger on the interior of the threaded rod. A third rod is fastened to the center of the plate at the lower end of the spring from which point it extends vertically upward, entering the axial space in the threaded rod for about a half an inch (when the apparatus is unloaded) and makes contact with the lower end of the calibrated rod. The lower end of the calibrated rod is formed by a small screw adjustment which makes it possible to set this rod at such a height that the scale carried on it will indicate zero when the calibrated rod is pushed down in contact with the lower rod and the apparatus is unloaded. This is the zero adjustment.

In operation the cylindrical sand specimen is placed on the base of the apparatus directly under the plate carried at the lower end of the spring. By turning the threaded screw this plate is brought down on the specimen. After contact is made between the top of the specimen and the plate further turning compresses the spring, which in turn stresses the sand specimen and also causes the rod extending upward from the plate to push the calibrated rod out of the top of the threaded rod. When the pressure on the sand specimen becomes great enough to break it the spring will recoil leaving the calibrated rod in such a position that the indication of its scale at the top of the threaded rod is the pressure required to break the specimen in pounds per square inch.

The advantages of compactness and ease of operation are claimed for this apparatus.

In event the amount of deformation undergone by a specimen during loading proves to be of value in research work, Mr. Saeger has devised an apparatus for measuring this. It consists of an Ames Dial (an apparatus for measuring and indication by means of the rotation of a pointer very small changes in length) fixed to

the top cross piece of the machine and fitted with an extension rod which bears on the top of the plate which in turn rests on the top of the specimen. As the specimen contracts under load this motion is carried upward through the extension rod to the Ames Dial where it is indicated.

Dietert Shearing Test for Green and Dry Sands

A shearing test has recently been devised by H. W. Dietert of the U. S. Radiator Company for green molding sands. The apparatus he now employs is very similar to the hydraulic type apparatus he formerly developed and which was described in Part II of this paper. The new apparatus differs from the earlier apparatus only in having a higher capacity and being fitted with two pressure dials, one for measuring low pressures and the other for measuring high pressures. For making shearing tests the two circular plates originally used on the apparatus for compression tests have been replaced by two half circular plates, one of which is shrouded so as to form a cradle into which the sand specimen may be set which aids in centering the specimen. When the sand specimen is in position to be tested one plate bears against one-half of one face of the cylindrical specimen and the other plate bears against the opposite face of the other end of the cylinder. When force is applied the specimen is sheared down its center on a plane passing through its axis. This shearing force is measured by the pressure gage of the apparatus as in the compression test. The low pressure gage is used in testing green molding sands.

In increasing the capacity of the apparatus by providing the high pressure gage, Mr. Dietert has enabled it to be used in testing baked molding sands. The test performed on these is exactly the same as that performed on green molding sand with the exception that higher forces must be employed because the baked sands often have substantially higher strength than the green sands. Sand cores made with the A. F. A. permeability rammer and baked at a temperature a little above the boiling point of water for one hour are used. In the testing of baked molding sands Mr. Dietert makes what appears to be a very valuable point by his contention that it is the strength while dry rather than the strength when green that determines the resistance of the sand to washing.

It has been found by Mr. Dietert that it is impracticable to provide a small testing apparatus suitable for testing green molding sands with enough power to break in compression or shear two-inch cylindrical specimens made of baked oil-bonded core sands. He has therefore adopted an ingenious method for making tests of this class of sand on his recently developed apparatus. The procedure consists of forming a cylinder (the standard permeability cylinder is used) and sawing it exactly half way through in a transverse direction at the middle with a special saw cutting rather a wide kerf. The saw and specimen holder required are special attachments for the apparatus. The sawed specimen when baked is placed in the testing apparatus with one half-plate of the apparatus so turned that both half-plates bear against corresponding halves of the two ends of the cylinder which are also on the side where the cut was made half way through the specimen. As pressure is brought to bear on the specimen it is broken by a flexure force through the center transverse to its axis and at the section where the saw cut was made.

Bond Test for Oil Bound Core Sands

At the University of Michigan considerable research work has been accomplished on the properties of core binders. For the purposes of this work new testing methods have been derived, one of which is of especial interest. This test, made to determine the bonding power of core mixtures before baking, differs from any other strength test of foundry sand so far devised and resembles certain tests proposed for determining the consistency of cement mortars. The test* consists of preparing a hemispherical test specimen and determining how much pressure is required to force a certain sized cone to a certain depth in it.

The apparatus for preparing the test specimen consists of the necessary core box and surplus frame, and a jarring stand which gives to each specimen a standardized amount of jarring. The surplus sand is cut from the top of the hemispherical specimen (which has a radius of about 2 inches and is molded with the convex side downward), the specimen is inverted to rest with its flat

*See also page 560 of this volume.

side down on a glass plate upon which it is handled, and the core box removed.

The prepared specimen with its plate is placed in position under the cone of the testing apparatus. This cone is nothing but the sharpened end of a vertical steel rod about ¾-inch in diameter. The rod slides in guides with but little friction and has a tank fixed to its top into which a shot stream pours from a shot supply bin above. The shot serves to load the rod so that its point sinks into the specimen below. When this has taken place to the established amount an electric mechanism automatically shuts off the shot supply, after which the total weight forcing the rod into the sand is determined and the test result desired is found. The electric mechanism has been found necessary to shut off the shot, for any mechanical device would require some force to operate it and would introduce an error into the determination of the necessary force required to produce the given penetration of the sand specimen.

Such a test as this one was deemed necessary for oil bonded core sands because of their extremely small strength before baking. If a standard sand is used in the preparation of the test specimen the test is a test of the core binder.

For testing the strength of oil bonded core sands after baking the University of Michigan uses a simple cross breaking test.

Report of Sub-Committee on Grading of Foundry Sands

To Members of the American Foundrymen's Association:

The purpose and general policy of the sub-committee on grading and a report of its activities prior to October 5, 1925, were outlined in a report at the Syracuse Convention of the A. F. A. A brief review of these activities will be necessary to a full understanding of the work accomplished this past year, so will be given here.

It was recognized that the adaptability of any particular sand for a given purpose depended upon several characteristics, among them being grain fineness or texture, clay content, chemical analysis, permeability, bond, etc. Hence complete grading would involve classification according to each and all of these properties.

The sub-committee felt the necessity of proceeding cautiously in the matter of grading, so made an exhaustive study of available test data with view to determining what property or properties should serve as a basis for the first efforts at grading; 727 sets of test data, covering sands of all types and from nearly every section of the country, were classified according to fineness, clay content, bond, etc., and the relation of the various characteristics was studied. These classifications are given as an appendix to this report. They show that grain fineness and clay content are very important factors in determining the working properties of foundry sands. The permeability or openness of a foundry heap seems to be due to (1) the grain fineness of the sand, (2) the quantity of clay which it contains, (3) the moisture content, (4) the relative size of the grains or grain distribution, (5) the distribution of the clay on or between the grains, and possibly other factors. The bond strength or cohesiveness of the sand seems to be due to (1) the quantity of clay it contains, (2) the quality of this clay, (3) the grain fineness of the sand, (4) the moisture content, (5) the distribution of the clay on or between

the grains and possibly other factors. Some of these factors are not well understood and are difficult or even impossible to measure. The most important or predominating factors, grain fineness and clay content, however, can be definitely measured. Furthermore, grain fineness and clay content are definite and stable characteristics of sand, just as carbon content is a definite and stable characteristic of pig iron. This is not necessarily true of such properties as permeability and bond which result from the particular distribution of the grain and clay in a particular sample and hence are more or less unstable. The grain fineness and clay content of new sand carries into the foundry heap to which it is added, raising or lowering the grain fineness and clay content of the heap exactly as would be expected from mathematical calculation of the mixture. For example, a ton of sand, grain fineness 90, clay content 10 per cent, added to a ton of sand, grain fineness 110, clay content 20 per cent, will actually produce a mixture having a grain fineness of 100, clay content 15 per cent.

The sub-committee selected as the subject of its first endeavors the grading or classification of sands with respect to grain fineness, and later undertook classification with respect to clay content. These are by no means novel ideas. A number of producers are at present grading sands as to fineness, low numbers in general representing fine sands while higher numbers represent coarser sands. Furthermore, sands are now marketed by many producers as high bond No. 1 sands, medium bond No. 2 sands, etc., the bond terms referring in general to clay content. The need of a standard system of grading arises from the fact that no one system is used by producers or foundrymen in common.

Classification With Respect to Grain Fineness

The A. F. A. fineness test is made by first removing the clay substance and then screening the grain. The results are expressed as percentages clay substance and percentages of grain retained on each of nine screens and a pan. The first attempt at classification has to do with the grain only and is connected in no way with clay content.

The complete screen data convey information regarding the relative quantities of grain of various mesh sizes. Any average of these data would naturally fail to carry this complete information. Hence the first attempts at grading sought to make grade numbers express not only the average fineness of the sand grain but also the distribution of the grain on the various screens. Such methods were developed individually by H. B. Hanley, R. M. Bird, C. A. Hansen, and C. M. Nevin.[1] While differing in details, these methods were in principle the same. The screen data were plotted and the resulting graph was compared with a set of master charts. That chart which it fitted, or most nearly fitted, gave the grade number. Such graphs and charts are of great value in studying the grain distribution of a sand, but, unless the zones of the master charts are narrow, grade numbers based on these charts fail to carry definite information as to grain distribution. On the other hand, if the zones are narrow, a very great number of master charts are needed in order to include all the different types of sand, and questions of judgment may arise in fitting graphs to the charts.

C. A. Hansen later developed a very clever scheme[2] for grading which eliminates the element of judgment in classifying a sand with reference to grain fineness. This scheme was known as the *median index method.* Index numbers representing the screen numbers were plotted against cumulated percentages of grain. The index number, called the median index, at which the cumulative curve cut the 50 per cent ordinate, was taken as the grade number of the grain. This method definitely establishes a grade number. It should be noted in passing that although the data are plotted graphically, the final grade number carries no information as to the grain distribution.

Along with the above graphic methods for classifying sands, two calculative methods were considered. They were known as "average fineness number" and "coarseness number" methods. The former was very similar to the Scranton method[3] for calculating average fineness.

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[1] Nevin: *Notes on the Grading of Sand,* Trans. A. F. A., Vol. XXXII, part 2, pp. 182-219.

[2] Hansen: *Grading Molding Sands, Trans.* A. F. A., Vol. XXXIV, p. 373.

[3] Nevin: *Notes on the Grading of Sand,* Trans. A. F. A., Vol. XXXII, part 2, p. 193.

The weight of sand on each screen was multiplied by the mesh number of the screen through which it had passed, the products were added and their sum divided by the total weight of sand grain. The resulting figure was approximately the average mesh of the grain. This method was criticized, first, because the grain sizes were really not inversely proportional to the mesh numbers, but rather proportional to the sieve openings (wire dimensions are neglected), and second, because the fine material influenced the average fineness figure more than the coarse material; in other words the fine material was weighted. Methods were proposed by Ries and Rosen[4] and later by D. W. Trainer—who personally presented his method to the sub-committee—for obtaining an average fineness number which weighted the coarse material. In the former method, the weights of the material on each screen were multiplied by the dimension of the screen opening, while in the latter method the weights were divided by the mesh numbers and then added. The resulting figure was called the coarseness number.

The question arose as to which was proper. Should the fine material or the coarse material be weighted or should all grain sizes have equal weight in determining the average fineness number? It was found, by the way, that the median index method of Hansen could be readily made a purely calculative method and that it weighted neither fine nor coarse material.

In order to answer this question and see which method would yield results in harmony with the working properties of sands, three theoretical sands of the same median index were made from grain collected from numerous fineness tests. The average fineness, median index and coarseness figures were calculated and permeability and tensile strength measurements were made. Table 1 produces these data.

The experiment was varied with similar results as shown in Table 2.

The average fineness numbers show (3) finer than (1) and (6) finer than (4)—results which are in harmony with the perme-

[4] Mich. Geol. Survey, Annual Report, 1907, p. 50.

ability and tensile strength tests. The median index figures show (3) coarser than (1) and (6) coarser than (4). When charted the mixtures appear to be of equal fineness, but it is impossible to judge accurately by the charts. It was argued that these experiments indicate that the fine grain would be weighted more than the coarse in calculating an average fineness figure.

Table 1

	(1)	(2)	(3)	
On 6	0.0	0.0	0.0	
12	0.0	0.0	0.4	
20	0.0	1.3	5.1	
40	10.0	19.7	24.5	
70	80.0	56.0	40.0	
100	9.4	16.0	16.0	
140	0.6	5.8	9.0	
200	0.0	1.0	3.5	
270	0.0	0.2	1.2	
Pan	0.0	0.0	0.3	
Average Fineness	41.2	45.3	49.8	(3) finer than (2)
Median Index	3.5	3.5	3.5	Of equal fineness
Coarseness Figure	1.49	1.56	1.72	(3) coarser than (1)
Permeability (dry)	172	116	72	(3) finer than (1)
Permeability (tempered)	349	258	184	(3) finer than (1)
Tensile Strength (g/cm^2)	3.9	4.8	5.9	(3) finer than (1)

Table 2

Screens	Mean diameter in inches	(4)	(5)	(6)	
Thru 12 on 20	.0496	...	5	10	
Thru 40 on 70	.0124	100	90	80	
Thru 140 on 270	.0031	...	5	10	
Average Fineness		40.0	43.6	47.2	(6) finer than (4)
Median Index		4.0 (?)	4.0	4.0	Of equal fineness
Coarseness Number		1.43	1.55	1.68	(6) coarser than (4)
Permeability (dry)		228	158	103	(6) finer than (4)

No strength tests were made.

The "average fineness number" method outlined above weights the fine grain. A method proposed by Ross C. Purdy[5] for calculating a surface factor for comparing the fineness of samples of ceramic materials is very similar to the above method, weighting the fine grain in proportion to its surface area per unit weight. Inasmuch as the surface area of spheres, per unit weight, varies inversely as their diameters, he took as factors the reciprocals of their average diameters. He assumed that the average diameter of the grain on a given screen was the mean of the size of the opening in the screen through which it had

[5] Trans. Amer. Ceram. Soc., Vol. 7, p. 441.

passed and that of the opening in the screen on which it was retained. Factors determined by Purdy's method, or by a slightly more accurate method, that of J. W. Mellor,[6] form a series of numbers, which, upon comparison with the "average fineness number" factors, show marked similarity. The "average fineness number" factors, as mentioned above, are merely the mesh numbers of the screens used in the fineness test. These latter were therefore revised slightly to make them correspond more nearly to the Purdy series. In columns of Table 3 are given the A. F. A. Fineness Test series of screens and beside them a series of factors determined according to Purdy's method. The grain on each screen would be multiplied by the corresponding factor in obtaining the Purdy surface factor. At the right of the Purdy factors are the factors used in obtaining the "average fineness number" referred to above. The right hand column gives a revision of these factors which more nearly corresponds to the Purdy series of factors, so far as relative values are concerned.

Table 3

A. F. A. Screen Mesh	Purdy Factor	Average Fineness Factor	Revised Average Fineness Factor
6	5.05	1	3
12	10.1	6	5
20	20.2	12	10
40	40.4	20	20
70	80.8	40	40
100	142.0	70	70
140	200.0	100	100
200	285.0	140	140
270	400.0	200	200
Pan	667.0	270	300

If, now, we take the screen analysis of a sand, exclusive of clay substance, multiply the weight (or percentage) on each screen by the appropriate factor listed in the right hand column of Table 3, add the products and divide by the total weight (or percentage of grain), the resulting number may be taken as a measure of the average grain size or texture of the grain. After much discussion the sub-committee in session at Cleveland, Ohio, on Sept. 17, 1925, voted to tentatively adopt this method of determining a fineness index number and to proceed to develop a

[6] Searle: *The Chemistry and Physics of Clays and Other Ceramic Materials*, p. 57.

system for classifying foundry sands based upon this number. They further agreed to call this index number the *A. F. A. Grain Fineness Number.*

The following points regarding the A. F. A. grain fineness number are worthy of note:

(1) It weighs the fine grain more than the coarse.

(2) The grain fineness of a sand is approximately the number of mesh per inch of that screen which would just pass the sample of sand if its grains were averaged in size.

(3) The grain fineness numbers of various sands are approximately proportional to their surface areas per unit weight.

(4) Any screen series can be used without greatly affecting the result.

(5) It may be calculated directly on the screen data when arranged according to the Standard A. F. A. method, that is, grain plus clay equals 100 per cent, or when arranged so that the sum of the grain percentages alone equals 100 per cent.

(6) In case the A. F. A. series of screens is altered by omitting certain screens or adding others, the appropriate multipliers can be omitted or added as the case may be without seriously affecting the method or the value of previous work.

(7) No graph paper is required.

(8) The grain fineness number conveys no information as to the distribution of the grain on the various screens, shape of grains, etc.

C. A. Hansen has recently developed a method which, in operation, is very similar to that recommended by the sub-committee. This method yields a series of index numbers very similar to the A. F. A. grain fineness numbers.

Classification of Sands With Respect to Grain Fineness

The sub-committee next proceeded to establish grain fineness zones for the various classes of sand. Several systems of zones were proposed and discussed in a session at Ithaca, N. Y., on March 27, 1926. It was finally agreed to base the zone limits on the series of factors used in calculating the grain fineness.

Seven of the screens in the A. F. A. standard series have openings which form a uniform series. The opening in the No. 140 screen is twice the size of that in the No. 270 screen, that of the No. 70 screen is twice the size of that in the No. 140 screen, etc. In other words, the openings of these seven screens make a uniform 2-ratio series. The other two screens, Nos. 100 and 200, have been inserted between the No. 70 and No. 140 and between the No. 140 and No. 270 screens, respectively, so that the series between the No. 70 and No. 270 screens is a 2-ratio series. If we were to extend the 2-ratio through the entire series we would have several more screens and corresponding factors would have to be added to the series used in calculating the grain fineness. It was decided to use this completed 2-ratio series of factors as limits for the grain classes. Following is this series, the added ones in parenthesis: 10, (15), 20, (30), 40, (50), 70, 100, 140, 200, 300. These numbers are recommended by the sub-committee as zone limits for the various grain classes.

Table 4

Grain Class[7]	Grain Fineness Zone
No. 1	200 to 300
No. 2	140 to, but not including, 200
No. 3	100 to, but not including, 140
No. 4	70 to, but not including, 100
No. 5	50 to, but not including, 70
No. 6	40 to, but not including, 50
No. 7	30 to, but not including, 40
No. 8	20 to, but not including 30
No. 9	15 to, but not including, 20
No. 10	10 to, but not including, 15

At a meeting of the sub-committee held in Mansfield, Ohio, on June 25, 1926, considerable discussion arose as to the designation of the grain classes. Numbers from 0 to 00 to six or eight are in use at present to indicate fineness of sand, the lower numbers generally being applied to the finer sands. It was thought that confusion might result between the older system of grades and the new grain classes if these new classes were designated by the same series of numbers, so at a meeting of the sub-committee held in Detroit on Sept. 26, it was decided to employ the numbers 10, 20, 30, 40, 50, etc., instead of the digits 1, 2, 3, 4, 5, etc.[7]

[7] When this report was considered by the Executive Committee of the J. M. S. R. C. and the A. F. A. Board of Directors, they changed the series of grain classes to read 1, 2, 3, 4, etc. Table 4 is the grain classification finally adopted.

Classification With Respect to Clay Content

The sub-committee next undertook to classify sands with respect to clay content. Considerable discussion arose as to the width of zones for the various classes. It was the general opinion that the zones for low clay contents should be narrower than those for high clay contents, because small differences in these clay contents make marked changes in the physical properties of sands. There is, for example, a great difference between a sand containing practically no clay and one containing even one per cent clay, especially when such sands are used for core purposes. The clay class zones (shown in Table 5) designated by letters of the alphabet were therefore recommended.

Table 5

Clay Class	Clay Content Zone (Per Cents)
A	0 to, but not including, 0.5
B	0.5 to, but not including, 2
C	2 to, but not including, 5
D	5 to, but not including, 10
E	10 to, but not including, 15
F	15 to, but not including, 20
G	20 to, but not including, 30
H	30 to, but not including, 45
I	45 to, but not including, 60
J	60 to 100

Application of Grain Fineness and Clay Content Classes

As has been previously stated, the complete grading of foundry sands involves classification with respect to grain fineness, clay content, chemical analysis, permeability, bond strength and possibly other properties. The sub-committee on grading has attempted to classify sand with regard to the first two of these properties only, hence the grading is by no means complete. It is believed, however, that it covers sufficient ground to be of real value.

In order to grade a sample of sand with respect to grain fineness and clay content, the standard A. F. A. fineness test is first made. The grain fineness is then calculated according to the method described on page 498. The grain fineness and clay content figures determine the classification of the sample. A sample of grain fineness 85, and clay content 22, would be a

No. 4-G sand. A No. 3-D sand would have a grain fineness between 100 and 140 and contain between 5 per cent and 10 per cent clay.

A sand which is designated as a No. 3-D sand is by no means completely described. These letters should be accompanied by the name of the source or section of the country in which the sand was produced and possibly other information. Following are examples:

No. 3-D Albany sand.

Open No. 3-D Albany sand—this would indicate greater permeability than the average No. 3-D Albany sand.

Fine No. 3-D Sandusky (O) sand—this would indicate grain fineness probably between 120 and 140.

Coarse No. 3-D Bremen (O) sand—this would indicate grain fineness probably between 100 and 120.

High Bond No. 3-D Albany sand—this would indicate clay content probably between 7.5 per cent and 10 per cent.

The variety of grain finenesses and clay contents available in the sands of a given district are necessarily limited. For instance, the Albany sands nearly all lie in the No. 2 and No. 3 grain fineness classes, possibly a few in the No. 1 and Nos. 4 and 5 classes. As regards clay content they lie largely in the D, E and F classes, only a few in the C and G classes. Some districts produce only one or two grades of sand, while other produce a wide variety of grain finenesses and clay contents.

In selecting sands by grade numbers, it should be remembered that sands of the same grain fineness and clay classes differ widely in working properties. They are similar in grain fineness and clay content only. The grain distribution on the various screens may differ, the quality of the clay may differ, the distribution of the clay on or between the grains may differ, the silica, iron oxide and alumina contents may vary and in consequence of these variations the working properties such as bond strength, permeability, refractoriness, etc., may vary widely.

Complete grading would cover all these points. It is believed, however, that classification with respect to grain fineness and clay content carries far more information regarding a sand than does the present system of grade numbers, which varies so widely in use among the various producers and foundrymen. It is therefore respectfully recommended that the present tentatively adopted system of classification be applied to the sands which you are producing or using and given a thorough trial. Criticisms are certain to arise and should arise if our work is to be constructive. The sub-committee will welcome all such constructive criticism.

Respectfully submitted,

A. A. Grubb, *Chairman*,

Sub-Committee on Grading.

Appendix

The Sub-Committee on Grading found it necessary to make a very careful study of the sand test data available. This was done in main for two purposes, first, to insure that the results of its work would be applicable to the sands of the entire country rather than to those of a single section only, and second, in order to determine, if possible, the relation between the various properties of sand. This latter point was discussed in greater detail in the early part of this report.

Seven hundred twenty-seven sets of test data were therefore selected from the Trans. A. F. A., vol. XXXII, part 2, pp. 324 to 391, and vol. XXXIII, pp. 888 to 903, and from data submitted to the Sub-Committee by P. Willard Crane, of the University of Cincinnati, O. Sets of data which were incomplete as regards fineness, clay, permeability or bond tests were omitted. The geographical distribution of the sands studied were as follows:

Alabama	63
California	10
Maryland	3
Michigan	64
New Jersey	34
New York	58
North Carolina	39
Pennsylvania	39
Tennessee	68
Virginia	62
Illinois	135
Iowa	12
Kentucky	17
Wisconsin	64
Ohio	59
Total	727

The A. F. A. grain fineness figures for these samples were calculated by the members of the sub-committee. The data were then assembled and classified with respect to grain fineness, clay content, dye adsorption value, permeability and bond. Averages were then taken and arranged in tables. Upon examining these tables it was found that more definite information could be gained by further classification, so some of the groups were

further analyzed. For instance, all samples with clay content between 0 and 3 per cent were classified with respect to grain fineness in order to observe the variation in bond and permeability with grain fineness when clay content is constant. This secondary classification can, of course, be carried still further.

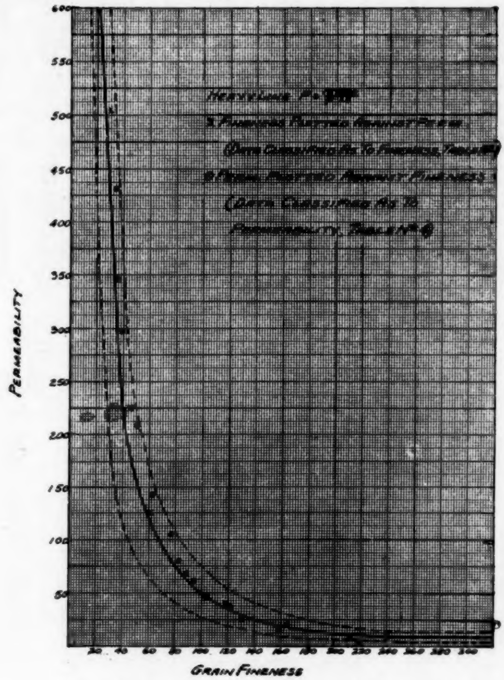

FIG. 1—PERMEABILITY VERSUS FINENESS

Discussion

Tables 1A and 3 show a marked relation between grain fineness and permeability. Upon plotting the permeability averages against grain fineness averages, it was found that the points laid very close to a curve represented by the equation

$$p = \frac{187000}{F^{1.8}}$$

This curve is shown in Fig. 1. Dotted lines on each side of this curve represent values within 50 per cent of the values

Table 1

A—Classified as to Grain Fineness

Grain Class	Fineness Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of D. A.	Dye Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
1	200–300	91	240	21.15	49	1,293	7.5	214	8.3	9.3
2	140–200	119	165	21.76	61	1,466	7.1	227	7.7	23.3
3	100–140	173	117	23.85	107	1,105	7.0	228	7.5	38.2
4	70–100	161	86	24.18	115	996	6.6	222	7.1	66.3
5	57–70	114	60	19.09	91	853	6.4	211	5.9	121.0
6	40–50	36	45	16.09	32	787	6.7	209	5.8	225.0
7	30–40	16	35	10.12	15	636	4.7	190	3.9	347.0
8	20–30	16	26	13.71	11	475	6.1	226	5.5	504.0
9	15–20	1	18	14.75	1	1,376	7.5	230	9.0	437.0
10	10–15	0	...	....	...	....	...	...	...	....

B—Classified as to Clay Content

Clay Class	Clay Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of D. A.	Dye Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
A	0.0–0.5	0	...	.....	...	....	...	...	...	.....
B	0.5–2.0	16	56	1.36	15	112	7.3	86	3.3	225.0
C	2–5	37	79	3.37	33	237	6.4	99	4.8	182.0
D	5–10	98	125	7.72	60	418	5.8	151	6.0	100.0
E	10–20	278	121	14.82	155	861	5.9	221	6.8	82.0
F	20–30	160	125	24.21	94	1,358	7.4	268	7.8	59.0
G	30–45	78	119	37.43	66	1,587	8.6	274	9.1	49.0
H	45–60	34	94	51.63	34	1,231	9.0	252	9.7	28.0
I	60–100	26	129	81.25	26	2,549	9.1	251	9.7	10.0

Table 2

Classified as to Dye Adsorption

D. A. Zone	No. of Tests	Grain Fineness	Per Cent Clay	Dye. Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
0–100	15	59	4.58	59	6.8	106	5.5	196
100–200	30	68	5.73	137	6.6	101	5.0	186
200–300	53	108	9.40	247	6.2	133	6.5	118
300–400	42	128	14.41	330	6.4	158	7.7	70
400–500	24	92	13.53	447	5.4	158	6.5	204
500–600	37	108	20.54	550	6.4	183	7.4	73
600–700	16	107	23.61	632	5.7	167	7.1	87
700–800	22	95	26.98	747	6.8	209	7.7	74
800–900	27	122	24.96	840	7.0	188	8.0	52
900–1,000	30	92	30.75	941	6.9	242	7.7	70
1,000–1,250	29	84	26.37	1,081	6.8	237	7.1	85
1,250–1,500	40	106	30.31	1,368	7.5	253	7.5	61
1,500–2,000	44	117	31.95	1,725	7.0	274	8.2	47
2,000–3,000	52	123	37.24	2,452	7.7	301	8.0	58
3,000–4,000	15	142	44.17	3,316	9.6	336	8.6	96
4,000–6,000	6	188	74.06	4,645	9.7	267	11.4	24

Table 3

Classified as to Permeability

Fineness Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of D. A.	Dye Ads.	Bond Str.	Perm.
0–5	25	221.0	44.6	11	2,733	229	3.4
5–10	65	212.0	31.2	39	1,531	221	7.6
10–20	116	158.0	24.9	69	959	208	14.3
20–30	96	131.0	24.9	68	1,074	221	24.5
30–40	51	119.0	22.2	31	1,111	235	35.0
40–50	62	104.0	20.6	40	976	222	44.6
50–70	75	95.1	19.8	46	1,031	231	59.5
70–90	54	83.6	19.3	36	1,149	238	78.8
90–125	65	75.7	17.2	48	988	234	105.0
125–175	41	64.3	12.7	31	793	201	144.0
175–250	35	52.5	12.2	32	928	216	210.0
250–350	19	38.8	9.5	14	371	194	298.0
350–500	15	34.4	12.5	13	718	209	430.0
Over 500	8	28.2	8.6	6	271	141	801.0

on the curve; 530 out of the 727 sets of data examined or 73 per cent of the data laid between the dotted lines. Clay content, distribution of clay, distribution of grain and other factors in addition to grain fineness no doubt determine permeability, hence the rather wide variation from the curve. It is evident, however, that grain fineness is the main factor and that the permeability of a sand can be estimated from its fineness.

Tables 1B and 3 show a very definite relation between clay content and permeability. By examining samples having very nearly the same clay content and classifying them as to fineness (Table 5) we can observe the relation between fineness and permeability at various clay contents. Similarly by examining samples having about the same fineness and classifying them as to clay content (Table 7) we can observe the relation between clay content and permeability in sands of various grain finenesses.

Table 4

Classified as to Bond (Transverse Strength)

Bond Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of D. A.	Dye Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
0–70	3	29	2.29	1	172	4.2	65	3.1	601.0
70–85	15	49	4.24	15	116	6.4	79	4.5	290.0
85–100	42	70	5.32	41	209	6.6	92	4.7	158.0
100–120	26	84	8.09	23	388	6.0	110	5.5	114.0
120–140	40	101	13.86	34	458	5.4	129	6.6	112.0
140–160	56	141	13.36	40	564	6.6	150	6.8	58.6
160–180	70	145	17.11	49	651	6.4	169	7.6	51.0
180–200	57	141	21.70	40	784	6.3	189	7.6	47.8
200–220	63	129	29.32	47	956	6.7	209	8.1	39.0
220–240	54	129	29.52	27	1,358	7.3	231	7.9	39.8
240–260	58	138	27.34	32	1,477	6.7	250	7.3	46.0
260–280	55	119	24.97	32	1,690	6.2	269	6.8	53.0
280–300	45	109	26.09	25	1,713	6.7	288	6.9	85.0
300–325	63	108	25.09	30	1,767	7.5	311	7.2	62.8
325–350	40	99	28.68	24	1,966	7.8	338	7.4	117.0
350–375	26	105	29.38	13	2,797	9.3	358	8.6	124.0
375–400	10	66	29.24	9	2,096	8.9	383	7.4	139.0
Over 400	4	73	24.65	3	2,592	10.5	424	8.4	141.0

An attempt was made to express by means of an equation the relation between permeability, grain fineness and clay content. Considerable difficulty was encountered in obtaining an equation of any practical value so an alignment chart was employed instead. This chart is shown in Fig. 2. A straight line through the grain fineness number of the sample as indicated on the left hand scale and through the clay content as indicated on the right hand scale cuts the permeability scale at a point which indicates the approximate permeability of the sample. This is

somewhat more accurate on the average than the curve of Fig. 1 which involves grain fineness and permeability only.

The alignment chart indicates the permeability that could be expected in a sample of known grain fineness and clay content under average conditions of grain and clay distribution. This average refers to the 727 samples of new sand examined by the

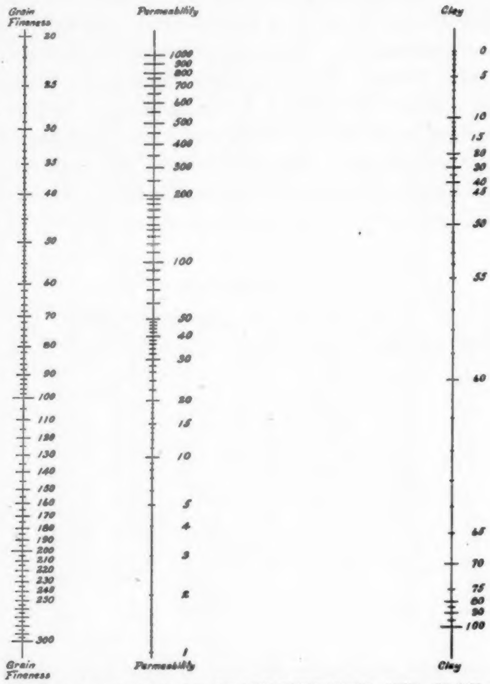

FIG. 2—SHOWING RELATION OF GRAIN FINENESS AND CLAY CONTENT TO PERMEABILITY

sub-committee. The writer has observed that the permeability numbers of some ten or twelve markedly different heap sands are uniformly tighter than the alignment chart shows for new sands. If these few observations are indicative of heap sands in general, then the clay distribution in heap sands is quite different from that in new sands; this very likely is the case. An align-

Table 5

Classified as to Fineness

Fineness Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of Samples Tested for Dye Adsorption	Average Dye Adsorption Number	Optimum Water for Bond	Average Bond	Optimum Water for Permeability	Average Permeability
A—Clay Content 0 to 3 Per Cent									
20–30	1	21	2.70	0	...	5.8	60	2.4	980
30–40	4	35	1.43	3	95	5.4	71	2.8	375
40–50	7	44	1.99	7	134	7.1	79	4.4	311
50–60	8	53	1.93	8	203	6.5	93	3.5	205
60–70	7	66	1.75	7	158	7.5	93	3.6	126
70–100	3	91	2.53	3	156	6.5	94	5.8	111
100–140	2	125	2.07	2	134	10.1	108	3.8	98
B—Clay Content 3 to 6 Per Cent									
20–40	4	32	4.88	4	295	4.6	112	4.0	428
40–55	5	50	3.59	5	287	6.5	94	3.1	209
55–70	6	61	4.69	5	214	5.9	95	4.4	141
70–85	6	77	4.66	5	229	5.7	96	6.4	107
85–100	4	93	4.73	3	245	6.9	104	5.3	66
100–120	4	107	5.25	4	393	5.4	109	5.8	58
120–140	2	127	4.70	2	404	6.8	139	6.9	68
140–170	3	166	5.20	2	174	7.3	147	5.7	18
170–200	0	...	....	0	...	...	...	...	...
200–240	5	216	4.94	0	...	8.3	151	6.0	15
240–300	1	276	5.00	0	...	8.0	173	6.0	7
C—Clay Content 6 to 9 Per Cent									
20–40	4	29	7.45	4	393	4.1	125	4.1	587
40–55	4	48	7.43	4	626	4.5	148	5.0	201
55–70	5	64	7.22	3	241	6.7	123	5.5	130
70–85	3	80	7.65	3	349	4.9	130	6.9	70
85–100	6	92	7.26	5	374	4.8	146	5.2	71
100–120	5	106	7.62	3	252	5.4	167	6.5	63
120–140	5	132	8.30	4	694	4.9	164	6.2	36
140–170	5	155	6.86	2	308	5.4	147	6.4	34
170–200	7	179	7.65	3	487	6.9	198	5.7	16
200–240	1	234	6.80	0	...	9.5	209	9.5	10
240–300	5	278	8.05	0	...	7.4	198	7.1	7
D—Clay Content 9 to 12 Per Cent									
20–40	3	29	10.28	3	363	4.6	137	4.6	853
40–55	6	44	11.03	5	553	4.4	186	4.9	261
55–70	8	61	10.68	6	473	4.4	175	6.0	163
70–85	10	79	10.68	5	448	4.4	186	4.8	79
85–100	7	89	10.88	3	285	4.8	157	5.8	65
100–120	13	109	10.45	8	536	4.7	184	6.0	42
120–140	18	129	10.40	12	741	5.4	164	6.3	32
140–170	13	155	10.18	6	470	5.8	169	7.4	20
170–200	5	189	10.14	1	244	6.2	175	7.0	16
200–240	5	213	11.02	5	576	7.7	163	8.1	11
240–300	6	269	10.31	1	440	7.5	182	7.8	7
E—Clay Content 18 to 24 Per Cent									
20–40	7	32	20.78	6	1,095	...	344	...	267
40–55	5	48	19.96	3	962	...	313	...	223
55–70	16	64	21.20	10	1,060	...	266	...	102
70–85	11	79	21.58	7	1,366	...	256	...	81
85–100	15	90	20.78	10	792	...	229	...	64
100–120	23	108	20.40	11	1,488	...	273	...	46
120–140	15	129	20.43	6	1,543	...	257	...	39
140–170	14	154	20.69	8	1,903	...	266	...	22
170–200	6	183	20.87	3	1,337	...	249	...	12
200–240	15	220	20.30	12	880	...	212	...	10
240–300	5	265	20.26	1	304	...	246	...	5
F—Clay Content 35 to 50 Per Cent									
40–56	3	53	39.45	3	1,349	...	309	...	109
56–70	5	61	45.25	4	718	...	265	...	41
70–85	7	78	41.14	7	811	...	211	...	32
85–100	18	91	41.34	16	1,106	...	271	...	34
100–120	16	108	41.91	14	975	...	248	...	34
120–170	5	148	40.93	4	1,677	...	307	...	40
170–200	5	178	43.42	3	2,743	...	299	...	43
200–240	4	214	38.32	4	2,506	...	308	...	13
240–300	6	271	41.07	5	2,391	...	274	...	9

Table 6

Clay Content 9 to 12 Per Cent—Classified as to Dye Adsorption

D. A. Zone	No. of Tests	Grain Fineness	Per Cent Clay	Dye. Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
100–200	2	94	11.76	158	4.8	117	6.7	54
200–300	14	88	10.18	249	5.7	132	7.3	161
300–400	8	108	10.50	332	5.3	165	7.4	164
400–500	6	98	10.32	445	4.2	131	5.3	262
500–600	8	126	10.53	550	6.0	157	6.5	48
600–800	3	127	10.74	608	5.3	133	6.7	28
800–1,000	5	139	10.98	860	5.2	164	5.7	32
1,000–1,500	7	105	10.79	1,220	4.6	204	5.6	77

Table 7

Grain Fineness 100 to 120—Classified as to Clay Content

Clay Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of D. A.	Dye Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
0–6	4	109	4.66	4	266	7.0	107	5.9	77.9
6–12	18	108	9.66	11	459	4.9	179	6.2	48.2
12–18	13	110	15.74	4	1,794	5.8	284	5.9	45.3
18–24	23	108	20.41	11	1,488	6.9	273	7.7	44.3
24–30	7	107	26.49	4	1,023	7.7	246	7.4	50.5
30–40	10	109	35.07	7	939	8.7	248	9.1	28.1
40–55	15	107	45.24	13	1,113	9.4	244	9.0	35.5
55–100	5	109	63.57	5	1,885	9.7	246	10.3	9.6

Table 8

Clay 9 to 12 Per Cent—Classified as to Bond Strength (Transverse)

Bond Zone	No. of Tests	Grain Fineness	Per Cent Clay	No. of D. A.	Dye Ads.	Opt. Water (Bond)	Bond Str.	Opt. Water (Perm.)	Perm.
0–100	4	58	10.86	4	282	5.5	88	5.1	393.1
100–140	21	94	10.18	18	395	5.3	127	7.0	120.4
140–160	19	156	10.30	12	538	6.4	150	7.6	28.4
160–180	17	150	10.58	9	545	6.0	168	6.9	40.9
180–200	10	127	10.22	6	724	4.7	190	5.2	136.5
200–220	7	139	10.79	1	304	4.6	209	5.6	33.1
220–240	6	113	11.30	2	1,248	3.9	231	4.8	53.3
240–260	5	136	10.82	0	....	3.7	250	4.1	45.4
260 up	5	58	11.23	1	1,436	4.6	297	4.6	155.9

ment chart similar to Fig. 2 but based on heap sands alone would be of great value to foundrymen in selecting sands to produce a desired permeability on their molding floors.

Tables 2, 4 and 6 show the relation between dye adsorption value and the other characteristics. In general, the more clay a sand contains, the higher is its dye adsorption value and the higher is its bond strength. For sands of the same clay content there seems to be an increase in bond strength with an increase in dye adsorption value, although the relation is not as definite as that between grain fineness and permeability.

Table 4 shows the relation between bond strength and the other characteristics. In general, there is an increase in bond

strength with addition of clay up to a certain clay content above which added clay fails to increase the bond strength but serves only to tighten the sand. That clay content which gives the best bond and permeability value seems to depend on the grain fineness of the sand. For instance, Table 7 indicates that for a grain fineness of 110 the optimum clay content is not far from 15 per cent.

The foregoing discussion refers entirely to new sands. There is much evidence to indicate that similar work on heap sands will show simpler relations and will yield more definite conclusions. Furthermore, our knowledge of the effect of grain shapes, grain distribution or uniformity of grain sizes and clay distribution on permeability and bond is very meager at present. If methods can be developed for expressing the shape of grains in numbers, and for measuring the uniformity of grain in a sample and for measuring the distribution of clay, then we can hope to develop either charts or mathematical expressions that will give us the working properties in terms of these variables. This will enable the foundryman or metallurgist to secure and maintain the desired working properties in his sand heaps just as he now obtains the desired properties in steel by mixing certain proportions of iron and carbon and then handling the mixture according to certain prescribed methods.

Respectfully submitted,

A. A. Grubb, *Chairman*,
Sub-Committee on Grading.

Report of Sub-Committee on Conservation and Reclamation

To the Members of the American Foundrymen's Association:

1. Since the last report of the sub-committee on Conservation and Reclamation, there have been added to the committee two new members, viz.: O. G. Caverly, Singer Mfg. Corporation, Elizabethport, New Jersey, who is represented by W. J. Reichert, and J. Spotts McDowell of the Harbison-Walker Company, Pittsburgh, Pennsylvania, who has been represented by W. R. Rochow.

2. The committee in session at the American Foundrymen's Association convention in Syracuse voted that the two most important problems confronting it for the coming year, were the investigation of molding sand substitutes and the classification of spent steel sand.

3. By molding sand substitutes the committee had in mind clays both natural and artificially treated, loam and high bonded sands containing high clay contents, and clay of a high colloidal value which would take the place of ordinary molding sand in the molding sand mixture.

4. By classification the committee had in mind the separation of the various grain constituents to various degrees of completeness depending upon the requirements and use to which the treated sand was to be employed.

5. In order to more effectively handle these very extensive problems, the committee was sub-divided, Messrs. Capp (represented by C. A. Hansen), Hanley, Caverly, and Wolf comprised the group to study molding sand substitutes, and Messrs. R. B. More (represented by F. A. Downes), Campion, McKinley, and R. J. Anderson, the group to study the classification of spent steel sand.

6. After organization and consultation with various members of the committee, Mr. Hansen began a very elaborate investigation of various types of clay which might offer possibilities as molding sand substitutes.

7. This investigation covered some thirty-five clays and numbered among them many of the prominent clays that had already been used as molding sand substitutes. The following tests were conducted upon the clays:

Tensile Strength, Green
Compression Strength, Green
Compression Strength, Dry
Permeability, Green
Permeability, Dry
Density
Dye Adsorption
Clay Substance
Effect of Temperature on Dry Strength
Clay Indicies

8. In addition to the above laboratory tests, very recently Mr. Hansen's committee has tested a number of the various clays with Ottawa sand in an effort to determine the rate of defusion of various clays into the sand grain, namely: the time factor in refractoriness.

9. Parallel tests will be run by Mr. Saeger at Washington on duplicate cores in order to obtain further information in this direction. This seems to be a very important investigation, and has its very definite practical aspect in that some light may be thrown upon the so-called burning-on or fusing of sand onto the castings.

10. In spite of the fact that a large amount of work has been done, and a tremendous amount of data made available, the Committee hesitates at this time to go on record as to the merits of the several clays submitted, especially from the foundry standpoint. The tests, however, have shown many indications, which, it is believed, could be proved when the clays are submitted to actual tests in the foundry.

11. Mr. Hansen's sub-committee feels quite certain that both green and dry strength tests are essential in evaluating a bond clay. The list of clays has been arranged in their order of value as bond, subject to further confirmation at the foundry under practical tests.

12. Too much credit cannot be given to Mr. Hansen and his associates for the splendid work undertaken and completed at the plant of the General Electric Company on the subject of molding sand substitutes.

13. The Committee appointed to study classification of spent steel sands, under the direction of F. A. Downes of the Dorr Company, report progress, although due to serious illness and business which took its chairman to the Pacific Coast, the work has been necessarily handicapped.

14. There has been one meeting of the General Committee on Conservation and Reclamation, which was held at the laboratories of the General Electric Company on June 4th and 5th, 1926. Here, there was practically a full attendance of the entire committee on Conservation and Reclamation, together with Dr. Ries, Chairman of the Committee on Tests, C. M. Saeger, Jr., of the Bureau of Standards, and C. H. Wright of the General Electric Research Department.

15. Very comprehensive reports by the Chairmen of the Sub-Committee, Mr. Hansen and Mr. Downes, were made which covered in a preliminary way the work done upon clay bonds as indicated in the earlier part of this report. Figures on conservation were submitted by three of the members which indicated beyond a question of doubt the possibilities of molding sand substitutes.

16. The committee spent the entire first day in session, while the second day was devoted to an inspection of the various foundries of the General Electric Company. The committee met and had dinner with various members of the executive staff and the foundry organization, which was exceptionally pleasing. The chairman, on behalf of the committee, wishes to express publicly the appreciation of its members to J. A. Capp, chief of the test laboratories, through Mr. Hansen for the courtesy extended to them while at Schenectady.

17. While this was the only regular meeting of the committee held since last Fall, many of its members have personally

visited one another at the different plants which has tended to keep the committee in close contact.

18. Perhaps there are cases, in which the molding sand substitute is not an economy due to the character of the work involved or the low cost of raw material.

19. In conclusion the committee feels justified in expressing its opinion that conservation through molding sand substitutes has progressed to an appreciable extent during the past year.

20. There are to be presented at this convention a number of papers, some by members of our committee, on the subject of conservation and the practical application of clay bond, which, to some extent, may indicate the progress that has been made, concerning which the committee has been cognizant.

21. The committee regrets that a more complete report of its work cannot be made at this convention, but trusts that by next year much of the work will have been completed and will be available for the foundry.

22. The chairman wishes at this time to express his appreciation for the co-operation received in his endeavor to carry on the work of the committee.

Respectfully submitted,

R. F. Harrington, *Chairman.*

Report of Sub-Committee on Tests

To the Members of the American Foundrymen's Association:

It is now something over three years since the first report of this sub-committee was presented at the Cleveland meeting, and in that time there has been opportunity for trying out some of the tests presented by the committee. This has led to the sub-committee recommending certain changes for the purpose of improving some of the methods with respect to speed and technique.

In addition the sub-committee has also been considering other tests. Throughout its work the sub-committee has borne in mind the fact that all tests recommended should, if possible, be of such a nature as to be of a practical character, easily manipulated, and involve the use of apparatus which is as simple and durable as possible. The importance of these factors will, we believe, be appreciated by all. Furthermore, the methods of testing recommended should be as accurate as possible under the necessary conditions of use.

It may appear to some that the sub-committee has been slow at times in recommending or developing new methods or tests, but this was because we considered it desirable and necessary to give them a preliminary trial in order to be assured that they were reliable, before recommending them to the Association.

During the past year the Sub-Committee on Tests has not held many meetings, but there has been considerable discussion by correspondence, and much work has been done by individual members of the sub-committee, in trying out apparatus and methods, with the resultant feeling that some progress has been made.

Acknowledgment should here be made, and it is a pleasure to do it, to the U. S. Bureau of Standards, The Columbus station of the U. S. Bureau of Mines, and to the Mines Branch of Canada, at all of whose laboratories very helpful cooperative work has been carried on. The details of much of this will be found in the appendices attached to this report.

The committee feels encouraged to believe that the tests suggested, and the apparatus for making these sand tests, have been fairly successful if one many judge from the number of pieces of apparatus that are being used by different foundries and laboratories.

Before taking up the new recommendations, which the subcommittee has to make, we should like to make clear one point, regarding which some misunderstanding seems to exist, viz., that the work of the sub-committee has been directed entirely to the development of tests for determining or measuring the different properties of sands used in the foundry industry.

The sub-committee has not considered it to be within the province of its work to specify certain tests for sands used for certain classes of work, or to express any opinion regarding the limiting values of different properties, which sands for a given purpose should show.

We would like to emphasize again that the committee always welcomes any criticisms of the testing methods proposed. Several good suggestions have come from persons using the testing apparatus, and any comment, no matter how unimportant, will be given careful consideration. One reason for desiring everyone to send in a report of any apparatus which does not seem to meet requirements is because in some instances it has been found that the apparently unsatisfactory behavior of the machine was due to neglect to follow the instructions for its use.

The several tests, and the sub-committee's recommendations may next be taken up.

Fineness Test.—One of the objections which has been raised to this test is the time required for making it. The disintegration of the sand in a revolving shaker, as originally recommended by the committee, requires an hour. H. W. Dietert, a member of the sub-committee on tests, has found that the same degree of disintegration can be obtained by agitating the water-sand mixture in a machine of the milk-shake type (Fig. 1) for 5 minutes.

Tests made at the Bureau of Standards and at Cornell University (See Appendix A) have corroborated Mr. Dietert's find-

ings, and the Sub-Committee on Tests approves of using a milk shake stirrer in place of the rotary shaking apparatus originally suggested by the Committee. This means a saving of 55 minutes.

No recommendation is made at present for shortening that part of the test involving the removal of the clay substance by settling and decantation, but the matter is under consideration. If a saving of time could be made in this part of the process it would be very desirable.

In the original instructions for making the fineness test it was stated that a one-quart milk bottle or preserving jar could

FIG. 1—MILK SHAKE STIRRER USED IN SEPARATING SAND FROM CLAY SUBSTANCE

be used for settling out the clay substance. Since it is important that the column of water in which the settling is done should always be of the same height, and since the two types of vessel mentioned above are of unequal heights, the sub-committee recommends the elimination of the milk bottle, and advises the use of a standard quart preserving jar. This is filled to the base of the neck in each case.

Permeability Test.—This test appears to be the most widely used of any of those recommended by the committee, if one may judge from the number of A. F. A. permeability testing apparatus employed. To date about 170 of them are in use. This does

not include any of the earlier forms of apparatus described by the committee, or special types which may have been devised by individual foundries or laboratories.

On the whole the A. F. A. gasometer type of permeability apparatus appears to have served its purpose well. Occasionally fault has been found with its operation, but the investigation of such complaints has shown that the trouble is usually due to improper handling of the apparatus. This has led to the issuing of the following precautions, which have already been published in the A. F. A. *Bulletin.*

It will do no harm to repeat them here.

Orifices.—These should be kept clean at all times. If any dirt collects in them it should be removed with a soft wooden point, and never with a metal point or wire. This is because the orifices are carefully drilled to exact size and any scratch will vary the size of the opening. Care should be taken to see that no moisture collects in them, as even a film of water will change the calibration. In case of doubt regarding the presence of moisture, blow a current of dry air through the opening.

Attention should be called to the fact that the orifice method for determining the permeability does not possess the accuracy of the standard method. In case there is any doubt as to which orifice to use, the determination can be checked against the standard method.

Leveling Machine.—In order to insure smooth descent of the bell the machine should be set level, and the weight that is placed on top of the bell should be set on the center of the latter. If the machine is used in the foundry it is desirable to have a small level on it.

Bell.—The bell should be raised slowly and not with a jerk, as the latter is apt to pull or splash water into the air outlet tube, and thus permit it to trickle down into the orifice with resultant stoppage of the latter.

Air-outlet Tube.—This should be kept dry. It is a good plan to wipe it out at frequent intervals with a rag fastened on the end

of a stick, in case any moisture has condensed on the inner surface of it.

Several changes have, however, been recently made in the apparatus to produce better operation, as follows:

The vent hole for drawing air into the bell has been enlarged.

The ramming head of the permeability rammer is provided with a slight taper upwards, to prevent sand sticking between the rammer head and the inside of the sand cylinder.

Attention is called to the fact that an expansion bulb manometer with scale can be attached to the apparatus in its present form, so that the permeability can be read directly from the scale, above mentioned.

The suggestion has also been made that the rammer be provided with a metal instead of wooden base to reduce any resilience that might diminish the impact of the blow. There is some question whether this would actually make much difference if the apparatus were set on a firm and non-yielding support.

Bonding or Cohesiveness Test.—The sub-committee feels that in using the above terms some confusion is likely to result, and recommends that the word *bond* be used for material, meaning the so-called *clay substance,* and that the word *strength* be used to designate the compression, tensile or any other kind of strength.

Method of Measuring Strength.—In the pamphlet on tests[1] issued by the A. F. A. in June, 1924, the sub-committee recommended a strength test, which is familiar to all by this time. We refer to the bar of sand pushed over the end of a plate. No major changes have been recommended in the method for making this test, except that since it was first described the method of expressing the strength is in terms of the actual weight of the broken pieces.

For the sake of clearness, Paragraph 11, p. 31, of the original pamphlet on tests, has been changed to read: "Take a sufficient quantity (approximately 1000 grams.) of sand, mix by hand, and transfer carefully into mold box with minimum ramming effect."

[1] Also published A. F. A. Transactions, .ol. 31, pp. 683-749, 1924.

This revised instruction it will be observed omits the use of a riddle for sifting the sand into the mold box, the reason for this being that it has been found that in riddling some very coarse sands there was a tendency towards an uneven distribution of the coarse and fine grains in the mold box.

Different Methods for Testing Strength of Sand.—Since the Sub-Committee on Tests has recommended the bar test (see pamphlet issued June, 1924) other strength tests have been tried, the two best known being those for compressive strength, and for tensile strength.

Both of these last two named tests have been under consideration by the Sub-Committee on Tests, and the following recommendations are made:

Compressive Strength.—It is recommended that the compression test shall be made on the green sand permeability specimen after it has been removed from the permeability cylinder, by applying a load uniformly to the two plane surfaces of the specimen, at a rate of 30 pounds per minute, with a leeway of 10 pounds per minute in either direction, the load to be applied along the axis of the cylindrical specimen.

If the test result of one specimen varies more than 10 per cent from the average of all this result must be discarded and another specimen tested. The compressive strength should be the average of 3 tests, and is expressed in pounds per square inch.

Attention should be called to the fact that the compression test is also applicable for determining the dry sand strength, or the strength of baked cores.

The sub-committee has not recommended any particular type of machine but there are several already in use, including the Dietert oil pressure apparatus,[2] the Adams moving fulcrum device,[2] and the Bureau of Standard helical spring compression machine[3]. Some laboratories have been using a lever type.

Attention is here called to the data in Appendix B, which

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[2] These two machines have already been illustrated, pp. 46-52, A. F. A. preprint 26-1 (1926). See also pages 449 and 453 of this volume.

[3] See page 535 for a description of the Saeger apparatus.

indicate that the rate of application of the load has comparatively little effect on the compressive strength of the sand.

Tensile Strength Test.—For this purpose a special cylinder,[4]

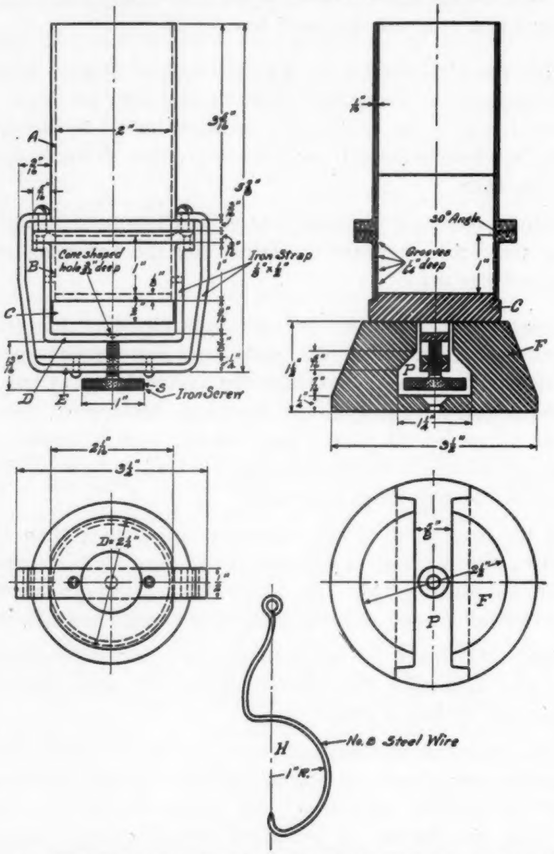

FIG. 2A—TENSILE STRENGTH SPECIMEN CYLINDER AND CLAMP (A. A. GRUBB)

consisting of an upper and lower half, held together by a clamp, is used. (Fig. 2A.) The internal diameter of the cylinder is two inches.

[4] Confer Adams, T. C., Strength Tests of Foundry Sands, A. F. A. preprint 26-1 (1926), p. 54. See also page 459 of this volume.

The permeability test specimen is rammed in this cylinder and after removing the cylinder with sand from the ramming machine, the clamp holding the two halves of the cylinder is loosened and

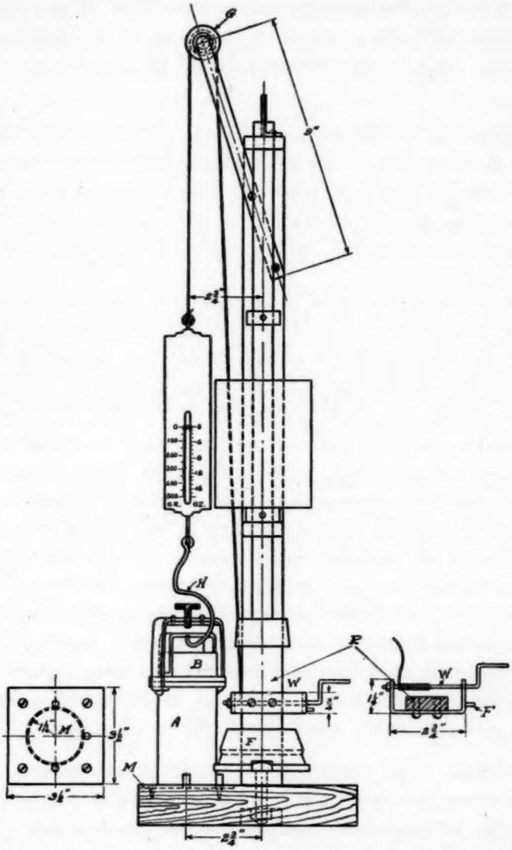

FIG. 2B—PULLING DEVICE FOR TENSILE STRENGTH TESTING (A. A. GRUBB)

these are pulled apart, in a machine (Fig. 2B)* devised for that purpose.

*Any other machine which pulls the core apart in the same manner and permits of applying the load at the same rate can be used.

The sub-committee recommends that the test shall be made by applying a load uniformly along the axis of the cylindrical test specimen at a rate not to exceed one pound per minute. If the test result of one specimen varies more than 10 per cent from the average of all this result must be discarded and another specimen tested. The tensile strength should be the average of three tests.

Comparison of the Strength Tests.—While it may be stated without showing any partiality that the compressive and tensile strength tests require less material, less time, and more compact apparatus than the bar or transverse test, the sub-committee does not make any preferential recommendation regarding the one to use.

The point that we wish to emphasize is that the compressive, tensile and transverse strength of foundry sands can be measured, but that in selecting which of the three tests to use in foundry work, it is for the foundryman to decide which test measures the kind of stress under which his sand is apt to fail. In other words, if he believes that the sand in the mold must resist compressive forces, and when it fails does so because of low compressive strength, then the compressive test is the test he should use.

If he believes his failures are due to low tensile strength, that is, inability of the grains to stick togeher, then he should measure the force required to pull them apart, namely the tensile strength.

All three types of test—transverse, tensile and compression—are being used at one or another foundry for control work. It is interesting to note that one foundryman may report that the compressive test meets his needs best, while another may claim that he gets far better results with the tensile test.

Optimum Water Content.—This term has been frequently used in connection with the permeability and strength of sands, and refers to that water content of the sand which gives the best permeability or best strength. As some misconceptions have arisen regarding the use of this term, the sub-committee thinks it desirable to call atention to the fact that the optimum water content does not necessarily mean the "best tempered condition," or that the optimum water content represents the best tempered point at which the sand is worked.

Core Test.—As various methods have been used to test the strength of baked cores, it seemed important to the sub-committee to ascertain if possible which was the best one, so as to obtain uniformity and efficiency in the method of testing.

As the subject was a large one, it was referred to a sub-committee of the Sub-Committee on Tests, which consisted of H. W. Dietert, Chairman, A. A. Grubb, and R. E. Kennedy.

The detailed report of this sub-committee is given in Appendix C at the end of this report.

By way of summary it may be said here that the sub-committee recommends molding the core mixture in the form of briquettes which are then baked. After baking and cooling, the tensile strength is to be determined, the results being expressed in pounds per square inch. In using the test to compare different core binders, which may possibly require different baking temperatures or different baking periods, separate lots of test cores are to be baked under different oven conditions as regards time and temperature.

Refractoriness Test.—Many inquiries have been received asking for information regarding a refractoriness test, and the problem is one to which your sub-committee has given considerable thought.

Several methods of attack have suggested themselves, such as determining (1) the fusing point of the sand as received; (2) the fusion point of the grain and bond separately; and (3) the temperature at which the sand begins to vitrify.

As the problem was a large one, outside cooperation was sought, and two laboratories, the Bureau of Mines at Columbus, Ohio, and the Mines Branch at Ottawa, Canada, offered their services. Fourteen different sands were selected, to make a series from coarse to fine grain, and high to low bond, and 100-pound samples of each were sent to the two bureaus.

The detailed reports submitted by the Bureau of Mines, Columbus branch, and the Mines Branch at Ottawa, Canada, form Appendices D and E of this report.

The following is a summary of their work:

Experiments Made at Bureau of Mines Station, Columbus, Ohio.—Cones of the sand as received, and of the separated clay substance were tested for refractoriness in oxidizing, slightly reducing and totally reducing atmospheres.

Bars 4 inches by 1 inch by ½ inch were also molded under standard pressures, the idea being to place them in a furnace on cylindrical supports, and heat them until the temperature was sufficiently high to make them sag.

While this latter test gave promise for strongly bonded sands, it was unsatisfactory with high silica ones, because in spite of all precautions the bars cracked and broke. This test was therefore abandoned as one of general application.

The recommendation of the Bureau of Mines, Columbus station, is that the sand as received and also the separated clay substance, shall be made up into cones and heated with standard cones in a pot furnace, allowing at least two hours to reach a temperature of cone 18 (2714 degrees Fahr., 1490 degrees Cent.) with from 4 to 6 per cent CO in the flue gases.

Before making any definite recommendation the sub-committee is awaiting the results of other tests.

Experiments Made at Mines Branch, Ottawa, Canada.—Here too the sand as received and the separated bond were made up into cones whose fusion point was tested in a reducing atmosphere.

Sag tests were tried, but were found to be successful only in the case of well bonded sands.

In addition the sands were heated to different temperatures and then examined microscopically to determine the changes that had taken place.

The Saeger test for sintering (described below) was also tried.

The data obtained by the Mines Branch will be very helpful to the committee in formulating a refractoriness test.

Saeger Sintering Test.—Another method for testing the refractoriness of sand is that reported to the sub-committee by C. M. Saeger, Jr., associate physicist, U. S. Bureau of Standards. It consists of applying heat to the surface of a bar sample of sand

for short intervals. The heat is supplied through a platinum ribbon, heated by an electric current. The ribbon is held against the bar for four minutes at a time, each contact being made at a different point on the bar, and at successively higher temperatures, until the sintering point of the sand is reached.

Use of A. F. A. Tests.—It is a source of gratification to know that the tests which have been recommended by the sub-committee on tests have been quite widely usd.

Up to date there is definite knowledge of about 250 permeability apparatus, over 100 compression machines, and over 100 impact machines for the bar test.

This does not include pieces of apparatus of the above types which have been made at different laboratories or foundries.

In order to obtain some more detailed information on the use of the A. F. A. tests the sub-committee sent out a questionnaire in April, 1926, to 114 companies or individuals who were known to have purchased sand testing equipment. The object of these inquiries was to ascertain among other things the extent to which the tests were used for foundry control, which ones were the most used, and also whether the foundries using these had set any limiting values for the different tests and classes of work.

Unfortunately the number of replies received was not large, but those that did come contained a number of interesting figures, which are received with appreciation.

The details of these replies indicate that about two-thirds of those that answered are using daily tests, and that the permeability test appears to be used more than any of the others.

Respectfully submitted,

H. Ries, *Chairman.*

Appendix A

DETERMINATION OF CLAY SUBSTANCE BY DIFFERENT METHODS

Results of tests made for determination of clay substance by disintegration for one hour in the revolving shaker, and for five minutes in a stirring machine.

I. TESTS MADE AT CORNELL UNIVERSITY, ITHACA, N. Y., TO DETERMINE PER CENT OF CLAY SUBSTANCE.

Sand	1 hour in rotary shaker Per cent clay substance Average	5 minutes in stirring machine Per cent clay substance Average
No. 1092 Camden, Tenn.	4.24- 4.16= 4.20	4.30- 4.62= 4.46
No. 676 Catawissa, Pa.	12.06-12.10=12.08	12.12-11.50=11.81
No. 661 South Mountain, Pa.	21.26-21.20=21.83	21.56-20.96=21.26
No. 678 Catawissa, Pa.	18.04-16.84=17.64	17.64-18.02=17.63

The above samples were selected to give a variation in percentage of clay substance. The stirrer used was a Polar Cub mixer.

II. TESTS MADE AT BUREAU OF STANDARDS, WASHINGTON, D. C.

Sand	1 hour in rotary shaker Per cent clay substance Average	5 minutes in stirring machine Per cent clay substance Average
Millville, N. J. (fine, weak sand)	5.32- 5.28= 5.30	5.35- 5.33= 5.34
Millville, N. J. (fine, strong)	18.36-18.35=18.355	18.37-18.36=18.365
Cedarville, N. Y. (Core sand)	.14- .14= .14	.16- .16= .17

The stirrer used was a Hamilton-Beach Shaker Apparatus, No. 8, which is illustrated in Fig. 1.

Appendix B

EFFECT OF RATE OF LOADING ON COMPRESSIVE STRENGTH OF SAND

The following data give the results of tests made by several members of the Sub-Committee on Tests to determine the effect of rate of loading on the compressive strength of sand.

I. Tests by W. M. Saunders, Saunders & Franklin, Providence, R. I.

The machine used was a slightly modified form of the one suggested by A. A. Grubb, using a spring scale.

The load was applied at the rate of 120, 60, 30 and 15 pounds per minute. Each figure represents the average of three to five tests.

Rate of loading Lbs. per min.	Strength with 6 per cent water Lbs. per sq. in.	Strength with 8 per cent water Lbs. per sq. in.
	Fine Albany	
120	2.00	3.5
60	2.01	3.2
30	2.01	3.4
15	2.00	3.1
	North River	
120	2.32	1.83
60	2.25	1.93
30	2.2	1.85
15	2.1	1.80
	Jersey	
120	5.77	4.74
60	5.32	4.93
30	5.29	4.77
15	5.00	4.74

II. Tests by H. Ries, Cornell University

The tests were made with the Adams compression machine.

Sample No.	Time in seconds in applying load	Rate of loading Pounds per minute	Strength of sands Pounds per sq. in. Average of 10 readings
1032	48.2	9—	6.74
	29.7	14±	6.93
	19.9	20±	6.81
1035	49.2	12—	9.12
	29.7	18±	9.31
	20.0	27±	8.93
6	30.6	15±	7.6
	17.6	25∓	8.56
10	51.5	12—	9.3
	29.7	18	9.07
	17.9	25	8.6
2	49.3	15	12.29
	29.7	27	13.87
	19.4	39	13.20
13	49.2	3	2.7
	29.7	6	2.8
	14.0	12	2.7
383	50	7+	6.05
	30	12	6.02
	20	18	5.94
390	47	5½±	4.30
	28	8	4.36
	19	13+	4.37
402	50	7+	6.59
	29	13+	6.6
	19	20±	6.75
1152	20	36±	12.40
	30	22±	11.78
	51	14±	12.08
385	20	7.5±	2.62
	30	5.0±	2.55
	46	3±	2.40
1536	20	49	13.90
	30	26±	13.60
	50	16±	13.80

III. Tests by M. A. Hosmer of Hunt-Spiller Corp., Boston, Mass.

The machine used was an Adams compression apparatus.

The materials employed were several samples of molding sand, of varying strengths and moisture contents, each sample uniformly mixed within itself.

In view of the difficulty in applying the load uniformly, we deal in this report solely with a constant speed of screw and do not attempt to apply a constant application of load in pounds.

In determining what rates of feeding we should use, we found that from the 0 point on the bar to a weight of 5-⅝ pounds,

it required 60 revolutions of the screw. We discovered that the fastest that we could turn the handle was 60 revolutions in 15 seconds. We also found that the slowest speed that would give constant application of load was about 60 revolutions of the screw in one minute. We, therefore, selected four speeds to be used in the work and they will be designated as follows:

Speed *a* 60 revolutions of screw in 60 seconds.
Speed *b* 60 revolutions of screw in 45 seconds.
Speed *c* 60 revolutions of screw in 30 seconds.
Speed *d* 60 revolutions of screw in 15 seconds.

Of course the screw would be turned at the same rate of speed after passing the 5⅝-pound mark as it did before it reached it. The figure of 5⅝-pounds or 60 revolutions was taken for convenience of the operator who followed the stop watch in applying the load at the various speeds.

The two things to be determined by the experiment were: first the correct speed to use in order to obtain true and consistent results, and second the effect of a variation in the speed one way or the other.

Discussion

Examination of the results of the averages obtained in column X shows that the fastest speed (*d*) in every case gives the highest results. It is also noticeable that the per cent variation from the average as shown in column Y is least in three out of five sands and second lowest in the other two sands using speed (*d*). This is undoubtedly caused by the fact that at this rapid turning of the screw the operator tends to stop after the bar has broken, at a certain position of the handle rather than at the exact instant the bar breaks. This speed, in the opinion of the writer, therefore, causes high results and is discontinued in the remaining tests.

Speed *a*, the slowest of the four speeds selected, gives in 3 out of 5 sands the lowest break of the four speeds and this is undoubtedly due to the longer period that the sand is subjected to pressure and the consequent earlier destruction of the bar.

As the remaining two medium speeds *b* and *c* give close results and approach the average of all the breaks on the sample,

any speed within this range should be satisfactory in the opinion of the writer, to use in operation the Adams machine. For our purpose the *c* speed would be more suitable as it would enable us to turn out the work in a shorter period of time.

Test 1

A—Heap Sand of 185 Permeability and Moisture of 8.5 per Cent

Speed	X—Ave.	Y Per Cent	Z Per Cent
a—60 revolutions in 60 seconds	9.88	1.9	5.06
b—60 revolutions in 45 seconds	10.00	3.0	9.52
c—60 revolutions in 30 seconds	10.03	2.8	8.43
d—60 revolutions in 15 seconds	10.35	1.7	4.76

Column X = Average strength of individual tests

$$\text{Column Y} = \frac{\text{Actual difference between the several breaks and}}{\text{X}}$$

$$\text{Column Z} = \frac{\text{Maximum load—Minimum load}}{\text{Maximum load}}$$

B—The test was repeated on a later day with the same type of sand having a permeability of 146 and a moisture of 8.9 per cent.

Speed	X—Ave.	Y Per Cent	Z Per Cent
a—60 revolutions in 60 seconds	10.63	3.53	7.86
b—60 revolutions in 45 seconds	11.07	2.42	8.51
c—60 revolutions in 30 seconds	11.25	4.44	15.15
d—60 revolutions in 15 seconds	11.58	1.36	4.26

C—A weaker sand was then selected as follows: Moisture 7.35 per Cent—Permeability 226

Speed	X	Y	Z
a—60 revolutions in 60 seconds	6.05	2.48	8.00
b—60 revolutions in 45 seconds	5.88	3.37	10.13
c—60 revolutions in 30 seconds	6.16	1.60	5.01
d—60 revolutions in 15 seconds	6.45	2.95	7.75

D—Sand of type (C) was repeated at a later date. This sand had a permeability of 243 and a moisture of 7.2 per cent.

Speed	X	Y	Z
a—60 revolutions in 60 seconds	6.52	2.89	10.71
b—60 revolutions in 45 seconds	6.60	5.66	14.70
c—60 revolutions in 30 seconds	6.85	1.17	3.57
d—60 revolutions in 15 seconds	7.33	3.27	11.12

E—Another type of sand of much more uniform quality and medium strength was then tried at the various speeds. Moisture 7.7 per cent.

Speed	X	Y	Z
a—60 revolutions in 60 seconds	7.38	2.71	8.07
b—60 revolutions in 45 seconds	7.31	2.56	8.13
c—60 revolutions in 30 seconds	7.16	3.91	11.47
d—60 revolutions in 15 seconds	7.53	1.43	4.84

In contrast to speeds *a* and *d*, variations from the averages as shown in columns Y and Z, for speeds *b* and *c*, are greater in general. This is, in the opinion of the writer, an indication of the true values obtained by speeds *b* and *c* because these sands which

are fairly open in character do consequently vary somewhat in sampling.

In short, the most advantageous speed that our laboratory has found for operating the Adams compression machine so as to give consistent results, is a speed of 2 revolutions of the screw per second.

Test 2

In this test two sands were selected (A and B) for compression determinations at different moisture contents.

Sand A was carefully sampled and a ¼ portion was taken and mixed by hand for 3 minutes. Moisture and compression tests were then run on this portion and the results recorded below in Table 1. The 3 remaining quarter portions were allowed to dry out and tests were then run on them and the results are shown below in Tables 2, 3 and 4.

Table 1, Sand A—Mixed 3 minutes by hand—Moisture 6.75 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	8.66
c—1st 5 pounds in 30 seconds	8.90

Table 2, Sand A—Mixed 4 minutes by hand—Moisture 6.90 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	8.92
c—1st 5 pounds in 30 seconds	9.33

Table 3, Sand A—Mixed 3 minutes by hand—Moisture 8.5 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	7.66
b—1st 5 pounds in 30 seconds	7.98

Table 4, Sand A—Mixed 3 minutes by hand—Moisture 8.5 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	7.52
c—1st 5 pounds in 30 seconds	7.70

Sand B was likewise carefully divided into 4 portions, each portion being allowed to dry out for a different length of time and each portion mixed by hand for 2 minutes. The results are recorded in Tables 5 to 8.

Table 5, Sand B—Moisture 8.1 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	7.56
b—1st 5 pounds in 45 seconds	7.72
c—1st 5 pounds in 30 seconds	8.17

Table 6, Sand B—Moisture 7.7 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	7.41
b—1st 5 pounds in 45 seconds	7.66
c—1st 5 pounds in 30 seconds	7.78

Table 7, Sand B—Moisture 7.35 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	7.66
b—1st 5 pounds in 45 seconds	7.94
c—1st 5 pounds in 30 seconds	8.00

Table 8, Sand B—Moisture 6.75 per cent

Speed	Ave.
a—1st 5 pounds in 60 seconds	8.00
b—1st 5 pounds in 45 seconds	7.78
c—1st 5 pounds in 30 seconds	7.94

Examination of results on sand A shows again that in the case of speed *a* the results are lower than speed *c* no matter what the moisture content may be, and this is also the case in sand B, except in one case (moisture 6.75 per cent). With this assurance the writer has adopted the speed of 2 revolutions per second temporarily for regular routine testing.

Further study of the above two sands in Test 2 shows that in the case of the sand that was dried out and wet up, the highest break that was obtained (speed *c*) was at a moisture content of 6.9 per cent; moisture content of 6.7 per cent and 8.5 per cent giving a weaker result.

In the case of the sand that started with 8.1 per cent moisture, the highest break was obtained at the start, but at 7.35 per cent moisture, the strength again increased and did not drop off again appreciably as the sand dried to 6.75 per cent moisture. There was not enough material to continue the drying out but it is evident that this sand could dry out quite a bit, from its original moisture content, and still retain considerable compressive strength.

Summary

It is not the writer's intention to discuss here the effect of the drying out and wetting up of these sands on the compressive strength and, therefore, no extensive results were obtained. However, in testing out for the best speed adaptable to our work the above sands varying in texture and moisture content are selected as suggested by Dr. Ries, and in each case the speed of 2 revolutions per second of the screw seemed to give the most consistent and uniform results.

VI. Tests by Bureau of Standards, C. M. Saeger, Jr.

The sands used were No. 00 Albany, Downer, Lumberton and

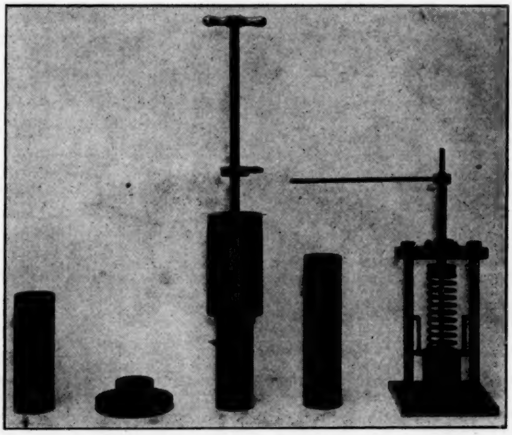

FIG. 3—SAEGER COMPRESSION TEST APPARATUS

Pettinos, tempered at different moisture contents ranging from 3 per cent to 8 per cent water.

The compression strength testing apparatus was of the spring type (Fig. 3), designed and constructed by the Bureau of Standards. It consists essentially of a helical spring mounted in a frame so that the unloaded spring will just make contact with the top of the sand sample. Load is applied to the sample through the spring by means of a screw. The indicator rod at the top

Table 1

Sand	Load, Pounds per Minute	Strength at 4 per Cent Moisture	Strength at 3 per Cent Moisture	Strength at 6 per Cent Moisture	Strength at 8.2 per Cent Moisture
Downer	14	7.3	6.4	3.5	2.4
Downer	26	7.2	6.5	3.4	2.2
Downer	45	7.2	6.2	3.4	2.2
Downer	80	7.3	6.9	3.5	2.3
Downer	111	7.0	6.5	3.7	2.4
Downer	185	7.3	6.4	3.6	2.4
Downer	290	7.2	6.8	3.7	2.4

Sand	Load, Pounds per Minute	Strength at 4 per Cent Moisture	Strength at 6 per Cent Moisture	Strength at 8 per Cent Moisture
Pettinos	14	11.3	7.8	4.5
Pettinos	26	11.3	7.8	4.5
Pettinos	45	10.6	7.7	4.8
Pettinos	80	11.0	7.5	5.1
Pettinos	111	10.9	7.6	4.8
Pettinos	185	11.1	8.0	4.6
Pettinos	200	11.2	7.8	4.8

Sand	Load, Pounds per Minute	Strength at 4.1 per Cent Moisture	Strength at 5.8 per Cent Moisture	Strength at 6.7 per Cent Moisture
Albany 00	14	3.2	2.6	3.4
Albany 00	26	3.1	3.2	3.5
Albany 00	45	3.2	3.2	3.5
Albany 00	80	3.2	3.0	3.7
Albany 00	111	3.2	2.9	3.6
Albany 00	185	3.1	3.0	3.4
Albany 00	290	3.2	3.1	3.3

Sand	Load, Pounds per Minute	Strength at 4.4 per Cent Moisture	Strength at 6.4 per Cent Moisture	Strength at 8.2 per Cent Moisture
Lumberton	14	12.45	10.20	8.0
Lumberton	26	12.50	10.25	7.9
Lumberton	45	12.55	10.40	7.7
Lumberton	80	12.60	10.20	7.1
Lumberton	111	12.50	10.20	7.2
Lumberton	185	12.60	10.20	7.3
Lumberton	290	12.40	10.25	7.3

of the screw shows how much the spring is deformed, which is translated directly into pressure pounds per square inch.

To establish variable rates of loading the crank arm attached to the screw was connected to a variable speed drill press. Seven rates of loading were tried on sands tempered at three moisture contents. The figures given (Table 1) represent an average of three tests.

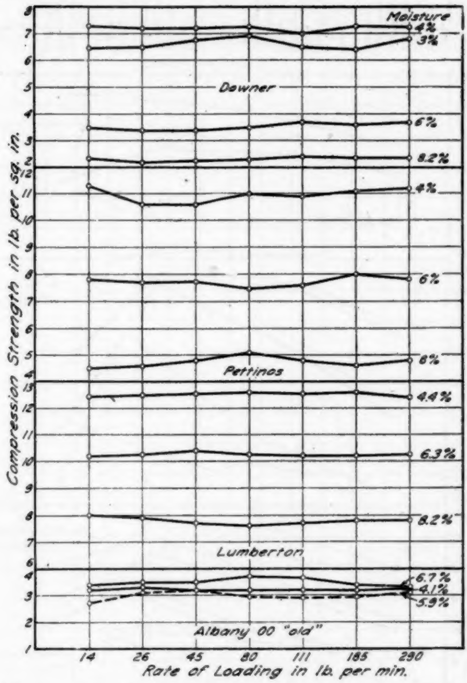

FIG. 4—BUREAU OF STANDARDS TEST RESULTS SHOWING COMPRESSION STRENGTH WITH DIFFERENT RATES OF LOADING

The Bureau states that the "Results of 273 compression tests at variable rates of loading and moisture contents determined on the spring type of compression testing apparatus, indicates no steady trend towards higher or lower results, even at very rapid rates of loading (consult Fig. 4). However, the effect seems to

vary somewhat with the sand and the moisture, which is probably to be expected in a system consisting of a liquid phase and a solid phase of variable grain size and contour.

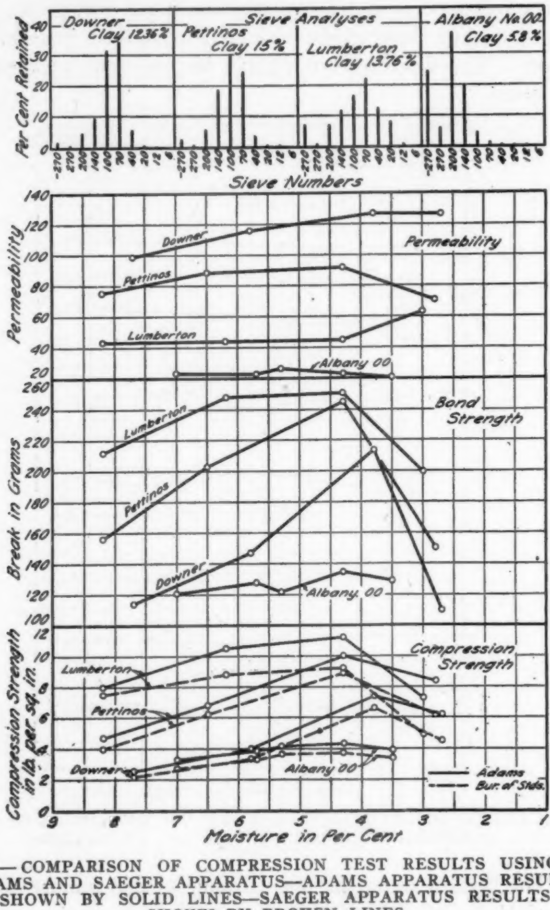

FIG. 5 — COMPARISON OF COMPRESSION TEST RESULTS USING THE ADAMS AND SAEGER APPARATUS—ADAMS APPARATUS RESULTS SHOWN BY SOLID LINES—SAEGER APPARATUS RESULTS SHOWN BY BROKEN LINES

The Bureau also ran a series of tests on the four sands at different moisture contents with both the Adams and Saeger compression apparatus. The results which are expressed graphically

(Fig. 5). They show that the two curves in each case are practically parallel, but that for some reason, not explained or known, the Adams machine in each case gave higher strength values than the spring apparatus.

Figs. 4 and 5 are charts graphically expressing the bureau's tests.

V. Tests by H. W. Dietert, Detroit, Michigan

Mr. Dietert used two sands, No. 2 Albany, and No. 4 Mills open (Ohio Red). The tests were made with the Dietert compression apparatus and the points from which his plotted curve was made, represents in each case the average of three tests.

Ohio Red Sand

Load Pounds per minute	Strength Pounds square inch
25	12.1
30	12.7
40	13.2
60	13.6
80	13.8
120	13.9
140	13.9

No. 2 Albany Sand

Load Pounds per minute	Strength Pounds square inch
10	2.9
20	3.3
30	3.9
50	3.9

APPENDIX C

REPORT OF CORE TESTING BY SUB-SUB-COMMITTEE ON CORE TESTING OF THE SUB-COMMITTEE ON TESTS

Introduction

The Sub-Sub-Committee on Core Testing wishes to submit to the Sub-Committee on Tests a summary of data obtained by a review of questionnaires, published material, and personal research and also certain recommendations for tentative adoption.

The first part of this report, Section A, will deal with discussion and classification of test methods used by various investigators. The recommendations will be contained in the latter part of this report as Section B.

Section A

1. *Sampling.*—Methods of sampling received no particular mention by any investigator. Samples tested may be divided into two classes, viz., regular mix used in production and special mixes for research purposes.

2. *Ramming.*—The methods employed to ram the core test specimens may be classified as follows: Hand rammed, drop weight rammed, vibrating and jolt rammed.

3. The test data submitted for hand ramming of the test specimen indicated that very consistent results are obtained by this method of ramming. The investigators found it desirable to have one party designated to ram all test specimens.

4. The ramming of core test specimens by the drop weight ramming device requires careful manipulation of apparatus and a further perfection of the apparatus to secure results, which are comparable with hand ramming in control work. From a research point of view, mechanical ramming will add much to the confidence one may place in test data submitted.

5. The electric vibrator is another method used to compact the core sand into test core box. Uniform test specimens are

obtainable by this method of ramming. Whether the jolting force of an electric vibrator is sufficient to overcome the variable green bond of various core sand mixes in order to ram all sands to a standard compactness is questioned.

6. The method of rapping core box by hand on bench or by an apparatus designed to accomplish this operation of jolting core sand firmly into the core box has proven to give fair results. Available test data on this method are very limited, but show good possibilities as a method which may be employed to ram core test specimens.

7. *Sizing of Specimens.*—Core boxes used were designed to necessitate securing one dimension of the test specimen by either of the three methods, viz., striking off core box; cutting core in core box and by using a pre-determined weight of core sand. The objections mentioned to striking off the suplus of core sand to the level of the core box are as follows: (a) The absorption of ramming energy by the variable excess of core sand; (b) The movement and the resulting re-arrangement of the core sand grains upon striking off because of inconsistency of test results.

8. A core box in which is incorporated a cutting device to cut test specimens to correct height will undoubtedly cause more movement and rearrangements of sand grains than the striking-off method.

9. The method of securing a rammed core test specimen by ramming a predetermined weight of core sand in core box to give the correct height is claimed to be justified by the increasing accuracy of test data. This method eliminates the absorption of ramming energy and also the disturbance of sand grains in the rammed specimen. Samples of core sand weighed within two grams of the predetermined weight will give mechanical rammed core specimens coming within the required tolerance.

10. *Handling of Core Test Specimen.*—As a rule, no particular attention is given to the core in removing and transportation of green core specimen. One investigator stresses this point and designed his equipment so that the core specimen is rammed on the core drying plate. This eliminates the abuse a test specimen may receive in transportation and removable operations.

11. *Baking.*—Test specimens are being baked in all kinds of core ovens and at just as varied a range of temperature.

The usual kinds of core ovens found in American foundries are used by many to bake the test cores, while others have constructed special laboratory ovens, heated either by gas or electricity. The most marked practice in the baking of test specimens is a specially constructed individual container equipped with thermocouple.

12. The time of baking and oven temperature was included in many of the test data submitted. Whether the temperature recorded with data is the average maximum or whether the oven used was capable of maintaining a constant temperature was omitted. The temperature at which cores are baked and the rate at which the cores are raised up to this temperature will undoubtedly affect the ultimate strength.

13. *Load Application.*—Core specimens are broken by subjecting them under loads to produce fracture in tension, flexure, compression and shear stresses.

14. The tension strength test is the most popular and exists in a fairly standardized state. Specimens of 1 square inch cross section area are almost universally used. The strength of the core in nearly every case is expressed in pounds per square inch.

15. Flexure tests suffer in standardization in that bars are broken on a variety of support distances, and, in addition to this, results of tests are expressed in unstandardized units.

16. Shear and compression tests may at present be regarded as having only a theoretic value. Other tests as conducted on cores are the moisture absorption test after baking and shrinkage test.

17. Since it is general practice in America to use the units of pounds per square inch, we wish to recommend that the committee approve as tentative standard practice that the strength of core be expressed in pounds per square inch fibre stress.

Section B

Dry Strength Test for Cores

Suggested Tentative Test Method.—Keeping in mind that the value of test results are dependent upon their popularity, and the directness with which they express the property in question, we recommend that the dry strength test for cores as outlined below be approved as a tentative standard practice.

I. Measure of Strength.

1. The tensile strength expressed in pounds per square inch shall be taken as a measure of the strength of dried or baked cores.

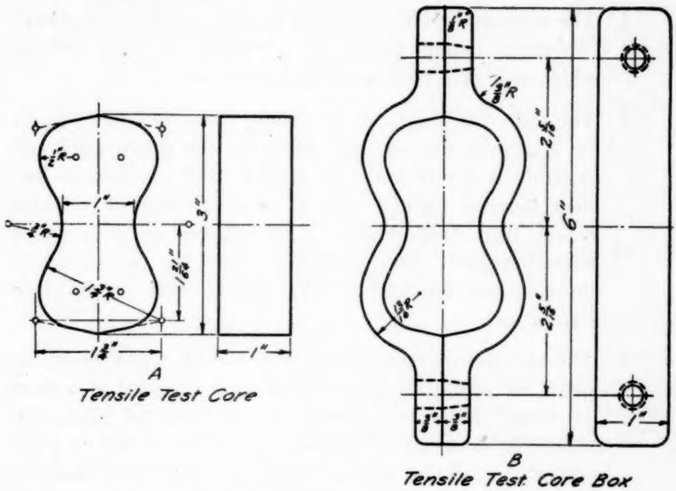

FIG. 6—TENSILE TEST CORE BOX AND CORE

II. Apparatus.

2. An open core box of the type and design shown at B, Fig. 6, shall be used for shaping the test cores. (This will be shown in printed report.) The box shall be made of metal in two parts, the parts fitted together accurately with dowels in such a manner that they can be readily separated. The inside dimensions of the core box are

shown at B, Fig. 6, and should be carefully adhered to. Aluminum or brass is recommended as material for the core box.

3. The dried cores shall be broken on a tensile device of approved design, several of which are on the market. The jaws which grip the core must be one inch or more in width and so designed that they grip the core firmly and evenly along the lateral surfaces. The machine must be capable of applying the load evenly and uniformly at a rate not exceeding fifty pounds per minute.

III. Procedure.

4. The core sand mixtures should be first properly prepared.[1] Moisture content should be controlled to that amount which will give best working conditions.[2]

5. The test cores are made by resting the core box (Fig. 6) on a smooth flat surface, filling in the green sand and pressing it firmly with the fingers until the box is full, then tamping lightly with a small wooden or rawhide mallet, then striking off to a smooth surface with a core maker's trowel. During this operation the two halves of the core box are held firmly together with one hand or clamp.[3]

6. The box and core are placed on a smooth surfaced drying plate, the box is opened and removed, one part at a time. If found desirable to move the core on the plate, this should be done while one-half of the box is left in place on the core, sliding the box with core rather than handling the core alone.

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[1] The committee recommends that in making comparative tests, mixtures should be made by using weighed quantities of dried sands and weighed quantities of binder, and that the mixture be thoroughly mixed by machine or hand. The mixture is then to be riddled three times through a ¼ inch mesh screen.

[2] Inasmuch as the optimum moisture content varies with different types of sand and binder and also because that moisture content which gives the greatest dry strength is not always desirable from the core maker's point of view, it is not practicable to give further directions regarding moisture content.

[3] It is granted that these directions for tamping may not result in a uniform density. In a core maker's hands, however, remarkable uniformity can be obtained, especially with core sands that are high in silica, such as are the most commonly used mixtures. It is recommended that methods of mechanical ramming suitable for standardization be further investigated with a view to adoption. The jarring method or tamping with the standard A. F. A. permeability rammer are possibilities.

7. If it is desired to mark the test cores for identification purposes, the marks should be made near one end of the test cores in order to not affect the strength of the test core at its narrower part.

IV. Baking.

8. It is impossible to give complete directions for baking which can be taken as standard for all kinds of binders. In cases where core sand mixtures are to be compared under similar baking conditions, the test cores from the several mixtures should be placed promiscuously on the same drying plate and baked together. This tends to eliminate a variable which might result from uneven oven temperatures. This system is applicable in comparing core sands and sand mixtures.

9. When comparing core binders which may possibly require different baking temperatures or different baking periods, separate plates of test cores, each containing several test cores of each mixture under test should be baked under different oven conditions as regards time and temperature. The maximum strength thus obtained will indicate the optimum baking conditions.[4]

10. After baking, the cores should be allowed to cool and should then be carefully inspected. Any test specimen showing any imperfection in the neck should be rejected. Each test core should be calipered for both dimensions at the neck. If either dimension is more than 5% off reject the test specimen.

V. The Tensile Test.

11. The test cores should be fitted into the jaws of the tensile machine in such a manner that they will be gripped uniformly along the lateral surfaces and so that the load will be applied along the line through their axes.

[4] The oven should, of course, be equipped with pyrometer or thermometer (the recording type preferred) and should be readily controllable. Ventilation is essential when baking cores bonded with oil or water soluble binders.

12. The load shall be applied gradually and uniformly at a rate not exceeding fifty pounds per minute.

13. The breaking strength in pounds per minute should be recorded and calculated to tensile strength per square inch as indicated in Section B, I, 1.

14. At least five test pieces should be made and tested. Briquettes that are manifestly faulty or give strength differing more than 15% from the average value of all the test cores made from the same sample and broken at the same period, shall not be considered in determining the tensile strength. The average of the acceptable values will be reported as the tensile strength of the group.

Respectfully submitted,

H. W. Dietert, *Chairman*,
Sub-Sub-Committee on Core Tests.

APPENDIX D

EXPERIMENTAL TESTS OF REFRACTORINESS OF FOUNDRY SANDS

The following report by K. E. Buck gives the results of experiments made by the Bureau of Mines at Columbus, O., for the purpose of devising a standard refractoriness test for molding sands.

A.—Report on Method for Determining the Refractoriness of Molding Sands

Introduction:

The problem of devising a standard refractoriness test for molding sands was requested of the Columbus Station of the Bureau of Mines by the American Foundryman's Association and this request was the basis for the following investigation.

Condition of Raw Materials:

It is probable that some of the cases of non-uniformity of refractoriness experienced heretofore were due to non-uniformity in the sand itself. This is deduced from the fact that some of the 100 pound samples received for this test varied greatly in their cone fusion temperature when samples were taken from different parts of the bag. If this is true, a carload is still more likely to vary and too much stress cannot be laid on the necessity of careful sampling. It is probable that a sample of at least several hundred pounds should be taken from different parts of each car and this amount carefully quartered down to approximately one pound.

Preparation of Sand for the Test:

Some of the sands as received contained small pebbles of quartz up to ¼ inch in diameter. As it was felt that these were not truly part of the sand and would be gotten rid of in practice, everything above 16 mesh was considered foreign material and discarded.

The remainder was made into cones both as received and ground through 65 mesh. The latter is preferable as it brings

all sands to approximately the same grain size. The deformation behavior of the 65 mesh cones is quite comparable to the material as received, although it is sometimes slightly lower.

The "clay substance" as found in the standard foundryman's test was also dried and a cone made up and tested.

Size and Shape of Test Piece:

In the preliminary work it was felt that a sag test should give an accurate differentiation between refractoriness of sands and considerable time was devoted to its development. Bars 4 inches by 1 inch by ½ inch of several different molding sands were tamped under standard pressures.

Dextrine was used as a bond. The bars were placed upon two cylindrical porcelain supports 1 inch apart which would allow

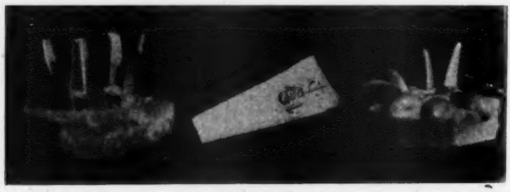

FIG. 7—THE CONE PLAQUE BEFORE AND AFTER FIRING—THE DARK CONES ARE SAND—THE LARGE STANDARD CONE IS SHOWN FOR SIZE COMPARISON AND TO SHOW HOW THE TIP WAS BROKEN OFF AND PLACED ON PLAQUE

movement without any dragging action, and fired in a laboratory kiln to cone 10. In each case where high silica sand was used, the bars cracked or broke. This was due to weakness of bars after the dextrine burned out and before sintering took place. This test was therefore abandoned as a test of general application, although for high iron sands it gave promise.

Standard cones 1 inch high with ⅛ inch sided triangular base were then made up of several sands. Dextrine was used as the bond. Their deformation was studied when placed in the furnace in both horizontal and vertical positions. A nearly vertical position with a slight inclination (5 to 10 degrees) toward the face of the cone was found preferable. This is similar to the refractoriness test used on clay and ceramic materials. (Consult Fig. 7.)

Atmospheric Conditions:

To determine the effect of atmosphere on the fusion point, tests were run in oxidizing, slightly reducing and totally reducing atmosphere. The results of these tests showed that the lowest deformation temperature of iron bearing sands is not obtained under either oxidizing or extremely reducing conditions, but is obtained at an intermediate point where the ferric iron is reduced

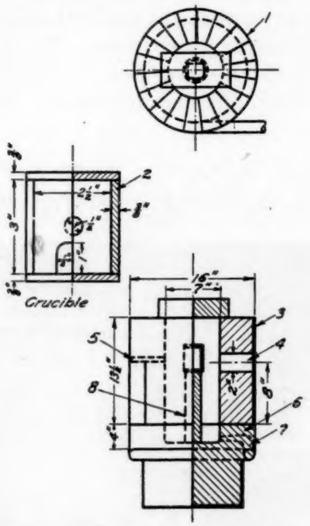

FIG. 8—DETAILS OF FURNACE USED IN TESTING FOR REFRACTORINESS OF SANDS—(1) ONE AND ONE-HALF LAYERS OF NO. 3 ARCH BRICK PLACED ON END AND THIN LAYER OF REFRACTORY CEMENT USED—(2) CRUCIBLE A CYLINDER WITH DISCS ON EITHER END, MOLDED BY HAND—(3) STEEL CYLINDER FOR CASING—(4) OBSERVATION HOLE, SHAPE SAME AS CROSS SECTION OF ARCH BRICK—(5) THERMOCOUPLE HOLE ½ INCH DIAMETER—(6) PLASTIC REFRACTORY AS IN (2) TAMPED IN TO COVER BURNERS, CUP DEEP ENOUGH TO REACH LEVEL OF BURNERS, FORMED BY HAND. SIDE OF POT BUILT UP WHILE BASE IS STILL PLASTIC TO INSURE GAS TIGHT UNIT—(7) BURNERS—(8) STANDARD SOAP BRICK FOR COLUMN.

to the ferrous state, forming ferrous-silicates. In the totally reducing atmospheres of a carbon electrode furnace, the iron was reduced to the metallic state and the fluxing action was diminished, producing a subsequent higher fusion temperature. This temperature, however, was not as high as that produced by an oxidiz-

ing atmosphere. That atmosphere which produced the lowest deformation contained about 4 per cent to 6 per cent CO and it is assumed that this also approaches the working conditions under which molding sands are used.

The fuel used in this laboratory was natural gas. (Typical analysis 95 per cent CH_4.)

In cases where artificial gases are used, CO and H_2 are present in addition to hydro-carbons. Theoretically, it follows then that the products of combustion for artificial fuels, giving 6 per cent CO, are more reducing per volume. This increase in reducing effect, when artificial fuels are used, is apparently not sufficient to give an appreciable difference in results.

The Furnace:

Gas furnaces of the pot type, muffle type (Meker), and an electric furnace of the carbon electrode type were used. In con-

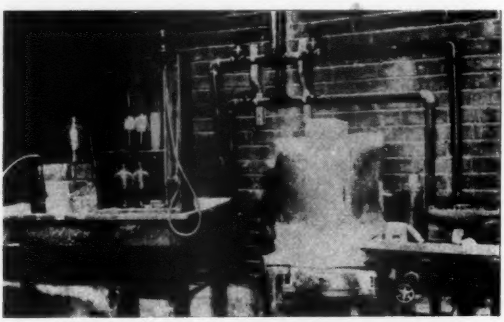

FIG. 9—THE FURNACE WITH ORSAT ANALYSIS APPARATUS AND POTENTIOMETER

sideration of original cost, maintenance, and case of operation, the pot furnace type is the most satisfactory. (Figs. 8 and 9 show the furnace used.)

The frame work and burners of an American Gas Co.'s No. 3 melter's furnace or a like apparatus furnishes a practical furnace at a low cost. The bottom or floor of the pot is built up with a suitable refractory such as 50 per cent kaolin and 50 per cent refractory grog 8 to 40 mesh, in the plastic condition. If the plastic refractory is built up over the burners, leaving a cup of

7 inch diameter and deep enough so that the blast from the burners is very close to the floor, the cylinder which furnishes the sides of the pot can be placed on this and seated so as to form a gas-tight unit. This cylinder is made of No. 3 refractory arch bricks encased by a sheet iron cylinder 16 inches in diameter by 13½ inches high. Using a thin layer of refractory cement it requires 19 No. 3 arch bricks placed on end to fill in the shell making a 7 inch inside circle. As the bricks are 9 inches long, a half arch brick is required on top of circle of whole bricks to make the required 13½ inches.

The Rate of Burning:

Due to the fact that a certain amount of time is required at a given temperature to complete the chemical and physical reactions, the test must not be run too rapidly or the reactions may not be carried to the same degree of completion throughout the cone. If the rate of firing is rather rapid, that is, if the temperature of the atmosphere is considerably higher than that of the cones, the deformation of the sand cone is slow in comparison to the standard ones. It sometimes extends over the deformation period of three successive standard cones. In the case of the cones made from "clay substance" in which a higher degree of homogeneity is found, the deformation is in some cases more rapid than the standard cones. Also, in the case of "clay substance" if the outside of the cone reaches the condition of fusion so that it seals the surface, the gases evolved from the interior can not escape and the cone will probably bloat and weaken its structure, causing deformation too early. These cases emphasize the importance of operating the test relatively slowly and using at least two hours to bring the temperature up to cone 18. A slower rate of heating than this has little or no effect on the deformation.

Standardization of Furnace:

It has been assumed that, in order to make a test practical for control work in a foundry, it is advisable to use a procedure which, after the first standardization, does not require the use of an Orsat gas analysis apparatus or a thermocouple and potentiometer.

Due to the fact that the gas used in various localities will

likely be different, the best way to describe such a procedure is to give the method used in this laboratory burning natural gas. From this, a test using another gas can likewise be standardized.

Procedure Used in Laboratory:

Atmosphere in the furnace was analyzed by use of Orsat apparatus. An analysis giving 4 to 6 per cent CO was always found when a flame 9 to 12 inches long escaped around a standard (9 inches by 4½ inches by 2½ inches) refractory brick which serves as a lid for the 7 inch hole of the furnace. This fact allowed a very close standardization of the gas analysis from the condition of the flame.

With the flame regulated as described, it was found that a certain degree of opening in the gas valve would give a rise in temperature sufficient to deform cone 18 in two hours. A calibrated valve is the most practical for this use. This is about the minimum safe time.

Results of a typical sand run under all conditions here in the laboratory:

Sand as Received		Sand Ground Through 65 Mesh		Clay Substance	
Oxidizing Cone	Reducing Cone	Oxidizing Cone	Reducing Cone	Oxidizing Cone	Reducing Cone
26-27	23	26-27	23	4	02

Table 1

COLUMBUS STATION INVESTIGATION

Refractoriness Data on Molding Sand

Sand No.	As Received Oxidizing	As Received Reducing	Ground through 65 mesh Oxidizing	Ground through 65 mesh Reducing	Washed through 200 mesh Oxidizing	Washed through 200 mesh Reducing
1	*14*	*11*	Sand as received thru 65 mesh		11	5
2	*16*	*12*	20	19	6	3
3	26–27	23	26–27	23	10	4
4	..	..	32—ground thru 100 mesh		..	..
5	..	..	32–33	..	..	..
6	*13*	12	Sand as received thru 65 mesh		11	*3*
9	*20*	23	*20*	23	23	23
10	*20*	23	Sand as received thru 65 mesh		15	11
11	*16*	19	23	23	26	26
12	*14*	*12*	*14*	*12*	14	*13*
13	*15*	*14*	Sand as received thru 65 mesh		13	*6*
14	..	..	33—ground thru 100 mesh		..	..

The deformation figures in italics are those obtained by Mr. Phillips.
The deformation figures not in italics are those obtained by Mr. Buck.

Conclusions:

The following seems the best method of conducting a refractoriness test on molding sand:

1. Obtain a sample which is truly representative.

2. Grind through 65 mesh, moisten with dextrine water and make a standard size cone 1 inch by 1/8 inch by 1/8 inch.
3. Place a refractory plaque composed of 50 per cent kaolin, 50 per cent calcined alumina with standard cones and heat in a pot furnace similar to the cone described, allowing at least two hours to reach a temperature of cone 18 (2714 degrees Fahr.) with from 4 to 6 per cent CO in the flue gases.
4. Make up cone from the dried "clay substance" as found by the standard foundryman's test and run as above.

These two values should give a close index of the refractoriness of the sand.

A Discussion of the Results

Sand No. 1: In this sand the deformation temperature noted as cone 14 and run by Mr. Phillips was checked exactly by Mr. Buck, using Mr. Phillips' sample.

Sand No. 2: The deformation temperature of cone 16 which was run by Mr. Phillips was checked by Mr. Buck, using Mr. Phillips' sample as being cone 17.

Sand No. 3: The results given here are those obtained on a carefully prepared sample obtained by quartering the entire bag of sand. This was done because there was a discrepancy between the work of Mr. Phillips and Mr. Buck and we desired to definitely find out the cause for it.

Sands Nos. 4 and 5: These are steel sands and contained no bond material.

Sand No. 6: There is apparently nothing unusual about the deformation behavior of this sample.

Sands Nos. 9 and 10: The difference between the work of Mr. Phillips and Mr. Buck in these sands is probably due to difference in the samples. It will be noted that sand No. 9 deformed at practically the same cone all the way through. This is also true of sand No. 12 and would seem to indicate that the low melting material was uniformly distributed on the grains of all the various sizes.

Sand No. 11: This is a very peculiar sand. It contained pebbles of considerable size and these were screened out of the material before the "as received" deformation test was run. However, in both of the other cases the larger pebbles were crushed and this probably accounts for the increased refractoriness with grinding which is unusual.

Sand No. 13: There is nothing unusual about the deformation behavior of this sand.

Sand No. 14: This material is a steel sand and contained no bond.

The inconsistency of the results between the two men who worked on this test seems to be due to a difference in the properties of the sand itself rather than the personal factor in operating the test. This stresses the necessity of getting an absolutely uniform sample.

When the first work was done on these materials we were under the impression that the samples sent to us had been quartered from a larger amount and were uniform and representative. Later when decided differences appeared in the fusion points we began to doubt this and proved by our work on sand No. 3 that the sample as sent lacked uniformity. Since this is the case the results cannot be considered as exact refractoriness values for the sands tested. The data, however, will show the approximate range and should be of interest.

It will be noted that most of our work on the bond was done by washing this material through 200 mesh. Somewhat late in our work we found that the A. F. A. already had a standard test for determining the clay substance and we ran a sample of this clay substance from sand No. 3. It proved to be similar to the material as washed through a 200 mesh screen and was therefore specified because it was felt that it would not only simplify the work necessary for making the test but that it was also probably nearer to the composition of the true bond material.

Ceramic Experiment Station, U. S. Bureau of Mines, Columbus, Ohio.

Appendix E

REPORT OF REFRACTORINESS TESTS MADE AT MINES BRANCH, OTTAWA, CAN.

In the following tests conducted at the ceramic laboratory at the Mines Branch, Canadian Department of Mines, for the determination of refractories in molding sands, it must be understood that the same stage of "heat punishment" was not measured in each case, but it was sought to find out what relationship, if any, might exist between the results obtained.

Cone Fusions

The softening temperature of the molding sand and also the softening temperature of the bonding material separated from the sand by the A. F. A. method, were determined by cone fusions. (Note: Ammonium hydroxide was used in place of sodium hydroxide in the separation of bonding material to avoid the introduction of fluxes.) The fusions were conducted in a reducing atmosphere instead of the oxidizing atmosphere usually specified.

Sag Test

This test was to determine at what temperature bending would take place in a bar of molding sand 4 inches by 1 inch by ½ inch when resting upon two supports 3 inches apart.

After drying the bars were placed on zirconia supports in a muffle furnace, heated at the rate of 100 degrees per hour, and the temperature at which they sagged to an extent of ½ inch was determined by means of a pyrometer. In low-bonded sands, the bars were insufficiently strong to support their own weight, and broke before sagging. In an attempt to overcome this difficulty, several sets of samples were preheated to 1000 degrees Cent., allowed to cool and then subjected to the sag test.

These preheated bars gave somewhat better results but it was evident that this method was not applicable to non-bonded or low-bonded sands.

(Preheating to higher temperatures would result in chemical reaction between the bond and the quartz grains which might be

expected to alter the temperature at which sagging would take place.)

Draw Trials

In order to study the progressive changes in the sands which take place during heating, thirty cylinders of each sand were placed on trays in a large muffle furnace and the temperature raised at 100 degrees Cent. per hour.

At predecided temperatures, three cylinders of each sand were removed from the muffle and allowed to cool slowly. These were microscopically examined and their crushing strength determined.

Method Suggested by C. M. Saeger, Jr.

The molding sand bars were subjected to the effect of electrically heated platinum strip. Each sand was given a series of heatings at increasingly higher temperatures until decided evidence of fusion was observed.

Comments

Cone Fusion

This test gives us the limiting temperature to which material may be heated before actual fluidity. In a molding sand this temperature would probably be much above that which would cause the first trouble in casting. The fusibility of the bonding material was determined by this method and compared with results of other methods in order to ascertain whether it might be taken as a measure of the usefulness of the sand. In some cases this appears to be so, but there were several exceptions.

Sag Test

The usefulness of this test is limited to the highly bonded sands.

Draw Trials

The microscopic examination of the test cylinders revealed changes which took place with the rise of temperature. It showed progressively the shrinkage of the bonding material, the cracking away from the quartz grains, the vitrification of the bond, the evidence of increasing fluidity, the attack of the glass upon the quartz grains and their gradual absorption by the glass. It also

showed the effect on feldspar and other low fusion minerals in the granular material.

The crushing strength at different temperatures reveals useful information.

This method calls for expensive laboratory equipment and consumes much time. For these reasons it would probably not be acceptable in the foundry but might have a place in commercial testing laboratories.

Saeger Method

By this method the changes taking place at progressively higher temperatures may be studied by a microscope or a strong magnifying glass and the varying degrees of refractoriness determined as in the case of draw trials. The temperatures, however, as indicated by this method, are somewhat higher than in the case of the draw trials, which may be accounted for by the fact that a much shorter period of heating is given and probably this method more nearly simulates the heating conditions obtained within a mold.

The ease of operation and the comparatively low cost of equipment are additional points to recommend this method.

HOWELLS FRECHETTE.

Methods for Determining the Properties of Cores Made with Cereal Binders

By H. L. Campbell,* Ann Arbor, Mich.

Cereal products have been used as sand binders from the earliest periods of foundry operations. Within recent years, new products obtained mainly from corn, have been placed on the market and have found extensive use as core binders. The chief characteristic of these materials is their bonding action produced both before and after baking the sand mixtures. A cereal binder is often used with other binders in making cores, because of its property of sticking the sand particles together before the cores are baked.

An important consideration in the selection of core binders is the cost per unit of bonding strength. In many applications, cereal binders have the advantage in this respect. As all cereal binders are marketed on the basis of weight, it is important that these materials be used in core sand mixtures on the same basis when comparative results are required. It has been found that the commercial cereal products vary considerably in weight per unit of volume.

In order to determine the relative values or most economical practice in the use of cereal binders, methods must be available for measuring the properties of cores made with these materials. It has been necessary to develop a method for determining quantitatively the bonding action produced by core binders before the cores become strengthened by heating. Also, a method for measuring the effects of cereal binders on the permeability of cores was required in the investigation of these materials. For obtaining the strength of baked cores, test specimens 1 by 1 by 8 inches were made in a uniform way and after baking for definite inter-

*Assistant Professor of Metallurgical Engineering, University of Michigan.

vals at specified temperatures, were broken transversely on supports 6 inches apart. It is well to point out the necessity for accurate control of the baking process when making comparative tests of core binders. Radiated heat should be avoided and provision made for obtaining uniform temperatures throughout the heating space.

Method for Measuring the Green Bond of Cores and Mixtures

The property of cementing the sand particles in a core sand mixture before the cores are baked is known as green bond. In all cases where intricate cores are made or where considerable handling of cores is necessary before the cores are hardened by baking, this property is of fundamental importance. On account of the relatively low strength of all core mixtures before baking, the preparation and handling of ordinary test specimens of green cores are exceedingly difficult operations. Methods which can be used for measuring the bond of molding sands may be unsuited to the measurement of this property in core sand mixtures.

The method which has been found most satisfactory for determining the values of green bond in core sand mixtures consists of forcing a cone of definite shape into a core of standard size and measuring the load required to displace a given volume of the core body. The action produced by the cone is to disrupt the sand particles and thereby separate the core into two or more parts. The more firmly the particles of sand are held together, the greater will be the load required to separate the components of the mixture.

Green Bond Testing Machine

The construction of the green bond testing machine is shown in Fig. 1. It consists of a frame made of ¾ inch angle steel to which is attached a wooden hopper and two wooden cross plates. At one end of a piece of ⅜ inch aluminum tubing is an aluminum cone having an angle at the point of 30 degrees. To the other end of the piece of tubing, an aluminum disk is fastened to serve as a support for an aluminum cup. This unit is guided vertically

by two roller bearings which are secured to the wooden cross pieces.

The load is applied to the cone at a constant rate by lead shot dropping from the hopper into the cup. A slide is provided below the opening in the hopper to control the flow of shot. In order to permit free movement of the slide, a diaphragm is placed in the hopper, having an opening somewhat smaller than the opening at the bottom of the hopper. The flow of shot is stopped in-

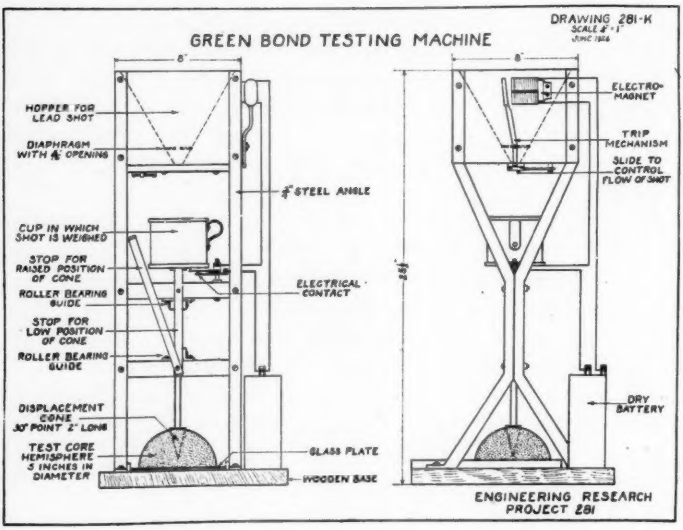

FIG. 1

stantaneously when the cone penetrates the test core a distance of 2 inches. By means of an electrical contact, the circuit through an electro-magnet is closed and this actuates a trip mechanism which closes the opening in the hopper. In order to protect the point of the cone, a stop is provided for the low position of the cone. Also a stop is used to support the moving unit in its raised position.

Green Bond Test Cores

It is necessary to make the test cores in a uniform manner. For this purpose, a core box having a hemispherical opening 5 inches in diameter is clamped to another box with a cylindrical opening 5 inches in diameter and 3 inches high. This assembly is mounted on a core making machine* and the sand mixture is jarred into the hemispherical cavity by 10 blows of the core making machine. After cutting off the excess sand, the core is turned out on a glass plate which is 6 by 7 inches. The plate with the body of sand is then placed on the wooden base of the green bond testing machine so that the point of the cone is directly above the center of the hemispherical core. The cone is lowered gradually onto the green core and the flow of shot is started. On the completion of the test, the weight of the cup and shot in the cup is determined and to this is added the weight of the moving unit. The values of green bond are expressed in grams.

Results of Green Bond Tests

The values for green bond of core sand mixtures prepared with cereal binders vary with the proportions of water used in the mixtures. Some results of green bond tests are given in Table 1. A mixture of 2250 grams (1500 cubic centimeters) of 60 to 70 mesh Michigan City sand and 45 grams (about 70 cubic centi- (1:21) meters) of a cereal binder was used in the tests reported in Table 1. These data indicate that the green bond increases with additions of water until the mixture becomes too wet to be used in core boxes.

Table 1

GREEN BOND VALUES IN GRAMS

Water added in cc	70	140	210	280	350	420
First Test	752	1,039	1,101	1,156	1,201	too
Second Test	760	1,001	1,064	1,140	1,214	wet to
Third Test	729	1,016	1,056	1,116	1,231	make
						cores
Average	747	1,019	1,074	1,137	1,215	

In Table 2 will be found green bond values for core sand mixtures prepared with different cereal binders. A ratio of 1

*Campbell, H. L., The Qualities of Commercial Core Oils, Trans. American Foundrymen's Association, vol. 33, 1926, pp. 72-82.

part by weight of cereal binder to 50 parts by weight of 60-70 mesh Michigan City sand was used in obtaining these data. The volume of water used in preparing the green sand cores was 4 times the volume of binder.

Table 2

Binder Designation	A	B	C	D	E
Average Green Bond Values in Grams	1,118	1,192	1,187	1,267	774

Method for Measuring the Permeability of Cores

One of the important requirements of dry sand cores is the provision for venting the cores. This property which is a measure of the rate of flow of gases through porous bodies is known as permeability.

The permeability of cores is generally of greater importance than the permeability of other parts of molds. In many cases the cores are almost completely surrounded with metal and the areas through which gases can escape from the cores are relatively small. Therefore the permeability of cores must be sufficient to allow the gases which are produced by contact of the molten metal with the cores, to escape freely. Otherwise, these gases will be forced into the metal, causing defects in the castings.

The apparatus used in measuring the permeability of dry sand cores in shown in Fig. 2. It consists of a cup in which a test core is placed, an air holder such as used in the A. F. A. standard test for determining the permeability of molding sands, and a connection between these units. Mercury is put into the cup around the test core so that the air which is delivered from the air holder cannot pass around the core. As a core will float in mercury, it is necessary to hold the test core down with a weight. By means of a brass sleeve which fits tightly over the rubber stopper on the air holder, the air supply is connected to the cup with rubber tubing.

Permeability Test Cores

The outside dimensions of permeability test cores are 3⅛ inches in diameter and 1½ inches high. At the center of one side of each core is a cavity 1⅛ inches in diameter and ½ inch deep.

These cores are made in a core box which is attached to a core making machine. The core sand mixture is jarred into the core box by allowing a head of 3 inches of sand to fall 10 times from a height of 12 inches.

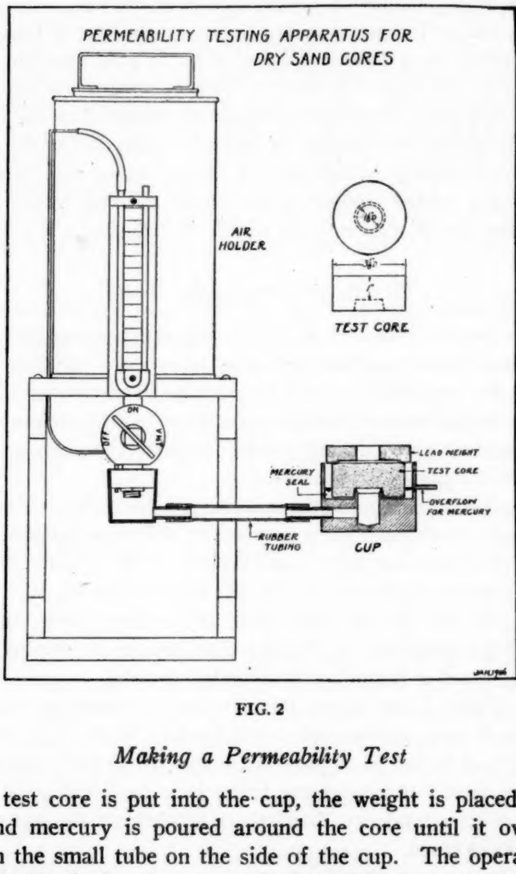

FIG. 2

Making a Permeability Test

A test core is put into the cup, the weight is placed on the core and mercury is poured around the core until it overflows through the small tube on the side of the cup. The operation of the air holder is the same as used when making permeability tests of molding sands. After turning the indicator on the valve to VNT, raise the bell to the mark X on the wall of the bell. Then

turn the indicator to OFF and the bell will remain in its raised position. When ready to start the test, turn the indicator to ON and the bell will lower as the air is forced through the core. With the aid of a stop watch, the time in seconds required for the bell to lower from the O mark to the 2000 mark is obtained. The water levels in the manometer are noted during the test.

The values for permeability are inversely proportional to the time required for a definite volume of air to pass through a definite thickness of core. In order to have numbers which can be readily compared, permeability values are obtained as the quotient of 100 divided by the number of seconds found during the test.

The air leakage in any part of the apparatus may be checked by placing a rubber stopper in the center opening within the cup and noting the change in level of the bell during a 5 minute interval.

Results of Permeability Tests

The results obtained in measuring the permeability of dry sand cores by the method described above are reliable, because there is no possibility of the air supply short-circuiting around the core during a test. Furthermore, there is little chance of damaging the test cores during baking, because the section through which the air passes is protected.

In order to determine the accuracy of the method, 6 test cores were made from each of a number of different batches of core sand. The following figures are typical of the results obtained—time in seconds; first core 10, 10, 10; second core 10, 10, 10; third core 11, 11, 11; fourth core 10¼, 10¼, 10¼; fifth core 10¼, 10¼, 10¼; sixth core 11, 11, 11. The average permeability value for these cores is found by dividing 100 by 10.4.

In Table 3 are given the average permeability values for cores made with commercial cereal binders in the ratio of 1 part by weight of binder to 50 parts by weight of 60 to 70 mesh Michigan City sand. It is apparent from these data that some binders have a greater tendency than others to obstruct the gas passages in dry sand cores.

Table 3

Binder Designation	A	B	C	D	E
Average Permeability	4.2	5.6	3.2	5.0	5.3

Dry Bond Strength of Cores Made with Cereal Binders

The bonding property produced by cereal binders can be determined most satisfactorily by transverse tests of cores which are made and baked under definite conditions. Methods and equipment for making test cores in a uniform manner and for measuring the breaking loads are described on pages 72 to 82 of the A. F. A. Transactions for 1926.

In order to obtain maximum results from cereal binders, it is necessary to use sufficient water in the preparation of the mixtures to dissolve and distribute the binder uniformly throughout the sand. The exact amount of water to be added will depend upon the condition of the materials used. As a general rule, the highest dry bond strength is obtained when the total water addition to dry materials is about 4 times the volume of the cereal binder.

The average transverse strengths of cores made with different cereal binders are given in Table 4. The test cores were made from mixtures containing 1 part by weight of binder and 50 parts by weight of 60 to 70 mesh Michigan City sand. In each test batch, the volume of water used was 4 times the volume of binder. The cores were baked for 1 hour at 350 degrees Fahrenheit.

Table 4

Binder Designation	A	B	C	D	E
Average Transverse Strength in Pounds	41	48	31	53	32

Summary

Methods have been developed for measuring the green bond of core sand mixtures and the permeability of dry sand cores. These properties, as well as the dry bond strength of cores, should be obtained when comparing the relative values of cereal binders or establishing the most economical practice in the use of any of the cereal binders.

Acknowledgment

The research on the development of methods for determining the properties of cores is a part of a program of studies on

core sands, binders and practice which is supported by certain foundry interests in Michigan and directed by the Engineering Research Department of the University of Michigan.

A Standard Sand for Use in Testing Core Binders

By H. L. Campbell,* Ann Arbor, Michigan

In the development of methods for testing core binders, it has been necessary to determine the influence of the size and shape of sand grains on the properties of cores. The purpose of this investigation was to establish a specification for sand which could be recommended for general use in testing core binders.

The sands which are used in foundries for making cores may be classified into two groups. In one group are those sands composed of clean grains of quartz or other rocks. The sands in this group are known as "sharp sand," "beach sand," "lake sand" or "river sand." In the other group are the sands which contain various proportions of clay. The clay-bearing sands are called "bank sand" or "molding sand."

Bank sands are used in core-sand mixtures mainly to strengthen the cores in the green state. When wet with water, the clay produces considerable bond. Cores with smooth surfaces can be produced by the use of sands containing finely divided particles. This condition is desired when the cores are used in molds for certain types of castings.

Some core sands are composed entirely of rounded grains, while other sands are angular in shape. The sand which is obtained from the Ottawa section of Illinois is composed of spherical grains of nearly pure silica. Michigan City sand and other lake sands generally contain rounded grains of quartz and feldspar. Sand which has been produced artificially by crushing rock contains irregular, angular shaped particles.

Sands Tested

Twenty-four representative samples of core sands were collected from natural deposits or from foundries and were tested for grain size. These samples were passed through sieves of

*Assistant Professor of Metallurgical Engineering, University of Michigan.

Bureau of Standards sizes. A 100-gram sample of sand was run 30 minutes in a mechanical sieve shaker machine and the sand remaining on each sieve was weighed. The results of some of the sieve tests are shown on Fig. 1. The more steep the curves, the greater will be the proportion of sand between the sizes specified. These data indicate that the predominating grain size for Michigan City sands lies between 60 and 70 mesh numbers; that is, the majority of the sand grains pass a 60-mesh

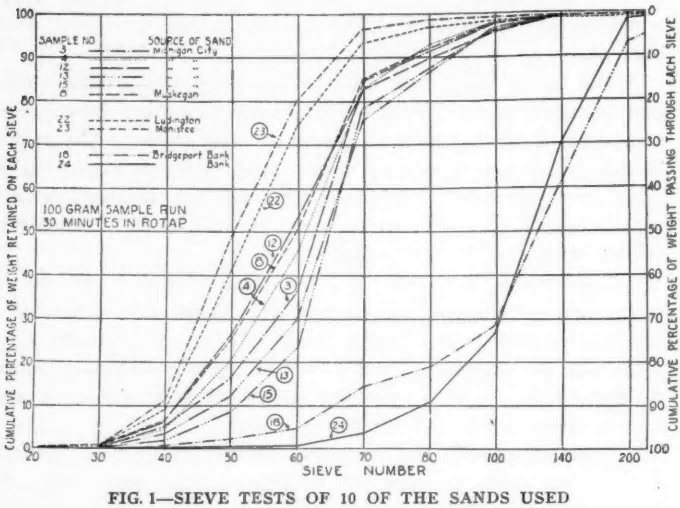

FIG. 1—SIEVE TESTS OF 10 OF THE SANDS USED

sieve and are retained on a 70-mesh sieve. Next in predominance is the 50-60 mesh size. It is interesting to note that the sieve analyses of the Michigan City sands are quite similar.

In order to establish definite practice in the testing of core binders, it is necessary to use a sand of limited grain size. A similar case of standardization is the universal use of 20-30 mesh silica sand in testing Portland cement. Before recommending the limits of grain size of sand for core testing purposes, it is important to determine the effect of grain size on the properties of cores. By keeping all factors constant, except the size of the

sand used, and measuring the dry bond and permeability of cores, it has been possible to arrive at the most satisfactory limits in the size of testing sand. A quantity of Ottawa silica sand, some sand having angular grains, and a large amount of Michigan City sand were carefully screened through sieves having openings of standard dimensions. Each sieve size was tested separately, using established methods * and equipment for this work.

Table 1

EFFECT OF GRAIN SIZE ON DRY BOND STRENGTH USING 1 TO 50 LINSEED OIL MIXTURES

Kind of Sand or Source	Size of Sand Sieve Limits	Average Transverse Breaking Load in Pounds
Ottawa silica	40–50	48
Ottawa silica	50–60	55
Ottawa silica	60–70	55
Michigan City	40–50	37
Michigan City	50–60	44
Michigan City	60–70	47
Michigan City	70–80	50
Columbia, angular	50–60	29
Columbia, angular	60–70	28

Effect of Grain Size on Dry Bond

The influence of grain size on the dry bond property of oil-sand cores is indicated by the data given in Table 1. The mixture used in these tests consisted of 1 part by volume of raw linseed oil and 50 parts by volume of sand. All cores were made in a uniform manner and were baked for 1 hour at 425 degrees Fahr. The time required for the oven to reach the desired temperature after the cores were put in, varied from 20 to 25 minutes. The values for transverse breaking loads given in the tables are averages of the breaking loads of six or more cores.

Other tests were made using 1 part by volume of raw linseed oil and 100 parts by volume of sand. The cores in this series were baked for 1 hour at 450 degrees Fahr. The transverse breaking loads of the cores made with different sizes of sand are given in Table 2.

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*Campbell, H. L., *The Qualities of Commercial Core Oils,* Trans. American Foundrymen's Association, vol. 33, 1926, pp. 72-82.

It is apparent from the data given in Table 1 and Table 2 that the dry bond strengths of oil-sand cores vary with different grain sizes of sand. There is a tendency for the strength to increase as the grains of sand become smaller. Cores made with an angular sand are considerably weaker than cores made with sand containing rounded grains of the same size. This is contrary to the general belief that angular grains produce an interlocking effect which strengthens the mass.

Table 2

EFFECT OF GRAIN SIZE ON DRY BOND STRENGTH USING 1 TO 100 LINSEED OIL MIXTURES

Kind of Sand or Source	Size of Sand Sieve Limits	Average Transverse Breaking Load in Pounds
Ottawa silica	40–50	20
Ottawa silica	50–60	20
Ottawa silica	60–70	20
Ottawa silica	70–80	23
Michigan City	40–50	13
Michigan City	50–60	15
Michigan City	60–70	17
Columbia, angular	40–50	7
Columbia, angular	50–60	6
Columbia, angular	60–70	6

Table 3

EFFECT OF GRAIN SIZE ON PERMEABILITY USING 1 TO 50 LINSEED OIL MIXTURES

Kind of Sand or Source	Size of Sand Sieve Limits	Average Permeability
Ottawa silica	40–50	10.0
Ottawa silica	50–60	6.7
Ottawa silica	60–70	5.0
Michigan City	40–50	9.1
Michigan City	50–60	7.1
Michigan City	60–70	4.8
Michigan City	70–80	3.7
Columbia, angular	50–60	8.3
Columbia, angular	60–70	6.3

Effect of Grain Size on Permeability

The permeability or venting property of oil-sand cores varies considerably with consecutive sizes of sand used in making the cores. This is indicated by the data given in Table 3 and Table 4. Permeability values were obtained as the quotient of 100

divided by the number of seconds required for 2,000 cubic centimeters of air at a constant pressure to pass through a core 1 inch thick, over an area of 1 square inch. The mixtures used in the tests reported in Table 3 contained 1 part by volume of raw linseed oil to 50 parts by volume of sand. The baking time was 1 hour at 425 degrees Fahr.

In Table 4 are given the permeabilities of oil-sand cores which were prepared from 1 part by volume of raw linseed oil and 100 parts by volume of the different sands. These cores were baked for 1 hour at 450 degrees Fahr. The permeability decreases rapidly as a finer grained sand is used.

Table 4

EFFECT OF GRAIN SIZE ON PERMEABILITY USING 1 TO 100 LINSEED OIL MIXTURES

Kind of Sand or Source	Size of Sand Sieve Limits	Average Permeability
Ottawa silica	40–50	10.0
Ottawa silica	50–60	6.7
Ottawa silica	60–70	4.2
Ottawa silica	70–80	2.7
Michigan City	40–50	7.7
Michigan City	50–60	5.9
Michigan City	60–70	4.8
Columbia, angular	40–50	11.1
Columbia, angular	50–60	7.7
Columbia, angular	60–70	6.7

Conclusions

From the results of the tests reported in Tables 1, 2, 3 and 4, it is concluded that sand for testing purposes should be limited to one sieve size. A greater range of size would involve difficulties in accurate permeability tests. The predominating grain size of the sand most extensively used for core making passes a 60-mesh sieve (size of opening, .0098 inch) and is retained on a 70-mesh sieve (size of opening, .0083 inch). Therefore, this size of sand is recommended for use in testing core binders. The 60-70 mesh sand produces cores of good structure and finish for testing purposes. On account of the difficulty of obtaining Ottawa sand of this specific size, a screened Michigan City sand which is clean and free from foreign matter is satisfactory. When tests are required on clay-bonded sand, a definite proportion of a specified clay which passes a 200-mesh sieve (size of

opening, .0029 inch) may be added to the 60-70 mesh Michigan City sand.

Acknowledgment

This investigation on core sands is a part of a research program including the study of core sands, binders and practice, which is supported by certain foundry interests in Michigan and directed by the Engineering Research Department of the University of Michigan.

Discussion

H. S. Austin: Mr. Campbell, how do you account for the greater transverse strength shown by the Ottawa sand and the Michigan City sand of the same size?

H. L. Campbell: Ottawa sand is cleaner and free from the very small amount of clay, dust, etc., which is present in the Michigan City sand and this probably accounts for the greater strength.

A. A. Grubb: Mr. Campbell suggests that on account of the difficulty of obtaining Ottawa sand of the size desired, a screened Michigan City sand would be satisfactory for use as a standard sand. It has been our experience that Michigan City sand is not as clean as Ottawa silica and furthermore, that sands sold under the name of Michigan City sands differ widely in their cleanness and in the strength of the cores produced. The A. F. A. dye absorption test seems to be a measure of the cleanness of a sand and of its oil absorption properties. Michigan City sands vary widely in dye absorption values. Ottawa silica is, therefore, certainly preferable as a standard. If it is found advisable to use Michigan City sand or any grain size fraction of Michigan City sand as a standard core sand, then specifications as to its cleanness measured by the dye absorption value or similar test should be made.

C. A. Hansen: I don't know but what probably I have done as much core binder testing as anyone and I have hunted around considerably for a suitable sand. Now your Michigan City sand is used a great deal locally in the making of cores, that is, around Detroit, Grand Rapids, Michigan City, and around the Western end of Lake Erie, but we have some foundries in the east and some in the west who have never heard of Michigan City sand. Personally I have used a very fine screened product which we get from the U. S. Silica Company, which works out, in my estimation, much better than the Michigan City sand. That particular sand will run mainly from 100 to 150 mesh. It is finer than most sands, it is a very clean sand, and I believe it is available in almost unlimited quantities. I can say it is a very good sand to use for core testing, and if anyone

wishes to screen that sand, rejecting the minus 140 and rejecting the plus 70, you will have still available for core testing half the sand you originally purchased.

CHAIRMAN W. J. KIHN: We should adopt some size. The nearest I can determine as the best size is 60 to 70 mesh sand. And it is going to be necessary for each one of us to use the one size, or otherwise the tests will be entirely out of range; it is necessary to use one sieve size.

Now when you get down to sands finer than 70 mesh, it is extremely fine sand. It is not characteristic of sand which is used most generally in this section of the country, although if there is any further information as to other sieve sizes which are more predominating, I think we should give consideration to those sizes. But we should decide on some one definite sieve size. Taking the situation at the present time, Mr. Hansen, would you say that 20 to 40 silica sand is better than the 60 to 70 mesh Michigan City sand?

C. A. HANSEN: No, I wouldn't say that.

CHAIRMAN W. J. KIHN: It is absolute folly to give results on core binders unless you specify definitely the materials which were used, consequently it is necessary right now to establish some kind of sand standards, so that we can compare our tests with your tests, so we can compare one plant with another plant. If anyone has some suggestions as to a better grade or size, this would be a fine time to consider it and if possible to standardize on some sand to be used. The manufacturers of Portland Cement would be in a turmoil if they tried to check tests from one plant with another if they did not all use 20 to 30 mesh Ottawa sands. The Ottawa Silica Company makes a business of supplying that sand. But no comparison could be made at all unless there was a standard for sand used in testing Portland Cement.

H. W. DIETERT: I have been looking at this Michigan City sand for some time. While it is a beautiful sand for core room work, I don't believe it would come up to the specification for testing sand. The purity of the sand does not come up to the standard to be in line with the other sands we have been using. The Michigan City sand will show a coating that you simply can't wash off unless you use acid. It is coated with an organic substance that you can't remove. Sodium hydroxide would not remove that entirely. And it would not come up to the standard in a fineness test. So that is one reason why I think we are not going in the right direction when we choose Michigan City sand. Those around Michigan City and this section of the country are acquainted with it, but the people in the east, in the west, and the south would be lost with Michigan City sand. But nearly everyone is acquainted with Ottawa silica sand, and I think the 60 to 70 mesh Ottawa Silica would make the best standard.

J. W. Bolton: I would like to ask Mr. Campbell if he intended to use that sand without sieving it for his standard tests?

H. L. Campbell: No, we don't use it without sieving.

J. W. Bolton: Well, it is very easy to obtain the Ottawa silica sands of almost any mesh you want; they are washed sands, they are nearly spherical in shape, they are almost round, and they lend themselves very well as testing sands. And as you are going to screen them anyway it would be better to use Ottawa sand rather than Michigan City sand. And then in doing that you would have your 60 to 70 mesh as a standard and you wouldn't have variations. The grains have a smooth surface and always you would have a more uniformly shaped sand.

C. A. Hansen: I have tested Michigan City sand, so far as that is concerned, and I have had direct comparisons between the different sands. And along the line of Mr. Campbell's point, with regard to the permeability of sands in making binder tests, I have tested something better than 50 different binders very carefully, running one test with one particular sand, and another with another particular sand. There weren't any of the binders tested with the same sand. And I would say the differences in permeability were wholly negligible. We played with every kind of binder you ever heard of, and made cores up to 2000 pounds compressive strength.

Major R. A. Bull: I am under the impression that Ottawa sand was selected by the cement industry because of its rather remarkable cleanliness. I am rather certain that it is a good deal cleaner than Michigan City sand due to its freedom from clay substance. And I think if the Ottawa sands are satisfactory, in their screened condition, for cement testing, they would be equally satisfactory for core testing.

H. L. Campbell: That point was given very careful consideration. We tried to get some 60 to 70 mesh Ottawa sand for testing purposes, and found it was practically impossible. We found there was quite a large proportion of the 20 to 30 mesh sand in the Ottawa silica deposits, but the 60 to 70 mesh size is in very small proportion. We tried to get certain of the silica sand companies to furnish some silica sand for research purposes and we couldn't get it. It was too much bother and too expensive. With the foundries having a large quantity of Michigan City sand on hand, do you suppose they would be interested at all in buying sand at 3 to 5 cents a pound, and then have to sort that sand out, which costs a good deal? This is a small item, maybe it doesn't amount to much, and maybe it is worth considering, I don't know—but would they consider at all buying sand at such high prices as against 30 cents a ton for Michigan City sand? Would it be considered at all possible to use that sand for testing purposes? That was the actual situation with us in getting the 60 to 70 mesh sand. It was more scarce than the 20 to 30 mesh size.

Now that is the situation in obtaining the Ottawa sand. If it were readily obtainable, there wouldn't be any question on the matter. But the difference in price on the Ottawa sand makes it somewhat prohibitive. Now maybe I am wrong on the point of the scarcity of that size of sand, but so far as we could obtain any information, it was extremely difficult or almost impossible to obtain. The small amounts which we did use were obtained from screening a large amount of the Ottawa sand from the Ottawa deposits. A large amount was necessary to get sufficient amounts of the 60 to 70 mesh size to make the tests reported in this paper.

H. L. Parr: It seems as though the main objection so far brought up to the use of the Ottawa sand lies in the difficulty of obtaining it. Did you try to get 50 mesh sand out of it, Mr. Campbell?

H. L. Campbell: We found the 50 mesh was much more easily obtained than the 60 to 70 mesh size.

H. L. Parr: I heard recently of a sand being put on the market known as a 50 mesh sand. I put some of it under a microscope and I would judge that there was a large quantity of 60 to 70 mesh obtainable from that sand. It has only been on the market a short time. This sand is very easily obtinable and it would remove the difficulty of obtaining the 60 to 70 mesh. I know this sand is now obtainable in car load lots and can also be had in 100 pound sacks, from a certain company in Ottawa.

J. W. Bolton: We started making 60 to 70 mesh out of 50 mesh sand four or five months ago. We just got a carload lot this week. And we find a large proportion of it is 60 to 70 mesh. In the 20 to 30 mesh sand, there isn't as much in that as we would like.

C. A. Hansen: I have made an analysis of that 50 mesh sand that Mr. Parr spoke of. The average is around 140 mesh. That stuff sells for around $5.00 a ton, f. o. b. Chicago, and I can say from my experience it is a very good sand, although when they put $10.00 freight on it to Schenectady, it puts it rather out of the question for us.

J. W. Bolton: The particular sand which Mr. Parr and I spoke about is a different deposit than referred to by these other gentlemen. Very little of that sand passes a 100 mesh screen, and it does have one very desirable property, and that is that it does stand wonderfully well in the green in core making.

I don't think you would have any difficulty whatsoever in getting a large proportion of the 60 to 70 mesh sand, if that is what you want, out of that particular deposit.

Member: I assume there have been a large number of tests made here in order to get these averages. And I notice what seems to me to be a peculiarity. That is, for instance, in the Ottawa Silica Company's

40 to 50 mesh, the difference in tensile strength is about seven pounds. The next jump, on the 60 to 70 mesh, there is no difference in the Ottawa. Now my impression would be that the strength is due to the area in contact, the size of the grain, or the area of the grain, or the area of the binder. And I wonder if Mr. Campbell has any explanation of that?

And, again along the line of the 140 mesh. I would like to know if any tests have been made from 130 right straight through to 140, to show where this curve would flatten out?

H. L. Campbell: I cannot state very much beyond the 40 to 80 range given here, although we did make some tests on coarser sands. When you get down to 30 it is entirely too coarse for test cores. It produces a very coarse structure and not adapted to general use. We made some tests below the 80 mesh size, and I am sorry I haven't the information with me at this time to indicate how those changes ran. That is, whether it continued to increase, or the strength decreased as the sand got finer.

Member: There seems to be a distinct falling off in the figures you have here.

H. L. Campbell: Yes, there does seem to be a jump there. I can't say just what is definitely the reason for that sudden change in the curve. The purpose of this information was mainly to bring out the difference that did exist between the different sizes. It is quite pronounced in some cases, and consequently it is not the best practice to use a 50 mesh sand. A 50 mesh size means anything which goes through a 50 mesh. There might be a predominance of 150 size.

H. W. Dietert: I would call one point to Mr. Campbell's attention. In Table 1, he shows an increase in strength in the green bond with the increase of moisture. And the way we find it is just the opposite. Of course, we don't know very much about the green bond, but we have a very delicate core to make, it is about two foot high and about two foot in diameter. Now about six or seven per cent of moisture will stand up, but if we increase the moisture to eight or nine per cent, it will slide off into the oven.

H. L. Campbell: We add just enough moisture so it will shape up nicely and not slide off as you say.

Some Properties of Core Oils

By C. A. Hansen,[1] Schenectady, N. Y.

Introduction

Buckle, writing some seventy-five years ago,[2] says:

"We are in the predicament that our facts have outstripped our knowledge and are now encumbering its march. The publications of our scientific institutions overflow with minute and countless details which perplex the judgment and which no memory can retain. In vain do we demand that they should be generalized and reduced into order. Instead of that the heap continues to swell. We want ideas and we get more facts. We hear constantly of what Nature is doing, but we rarely hear what man is thinking. Owing to the indefatigable industry of this and the preceding century, we are in possession of a huge and incoherent mass of observations which have been stored up with great care, but which, until they are connected by some presiding idea, will be utterly useless."

Further along, he says, with respect to certain geological theories which were later proven to be very faulty:

"They had the merit of provoking controversy, which was eminently serviceable to the interests of truth. For the great enemy of knowledge is not error, but inertness. All we want is discussion and we are sure to do well, no matter what our blunders may be. One error conflicts with another; each destroys its opponent, and truth is evolved."

These quotations may be interpreted, at the pleasure of the reader, as justification or apology for the manner in which the subject matter is here treated.

The various oils used as core binders in the foundry all depend upon one specific property of these oils,—the ability to coagulate to form tough, strong films. The coagulation may be the result of simple polymerization, i. e., the grouping together of several oil molecules to form more complex molecules without change in chemical composition, or it may be the result of tying several molecules together with interposed elements as bonds,—oxygen, sulphur, and the like, analogous to the processes of vulcanizing rubber. These coagulation processes progress very slowly at ordinary room temperatures, and they are accelerated by increasing the temperature; we bake our cores in order to bring about the necessary coagulation in some practicable time period, and we bake

[1] General Electric Co.
[2] Buckle, *History of Civilization in England.* Vol. 2, part 2.

our cores in an oxidizing atmosphere because the oxygen bonding process of coagulation is in general much more rapid than simple polymerization.[3]

Baking is apparently not essential to the development of strength in oil bonded cores except in respect to the time required. Ordinary paints depend upon this same property of oils; in paints the coagulation processes are accelerated by the addition of catalysts, more commonly called driers, since otherwise the fresh paint film would remain soft and tacky for perhaps weeks, subject to destruction by rain, dust, etc., but the paint text books state that the slow drying films obtained without the use of driers would afford better protection were it practicable to use them.

Vulcanization of oils by means of sulphur and the like is often resorted to in manufacturing oil bonded insulators, and a similar practice is not impossible in making cores. Vulcanization may also be accelerated by the addition of various catalysts and reagents, an almost universal practice in the rubber manufacturing industry. Leech[4] lists 94 such catalysts and reagents patented in the United States between 1874 and 1926.

It seems, as will be shown later, that the end result is much the same whether core oils are coagulated slowly at room temperatures, rapidly at core oven baking temperatures, by oxidation with or without driers, or by vulcanization processes; the end product for a specific oil seems to be a more or less constant affair chemically, or at least physically, with specific physical properties, including a specific strength.

In common with all other hydro-carbons and carbo-hydrates, oils and their coagulation products are destroyed by oxidation or distillation if the baking temperatures are too high; and the rate of destruction increases rapidly as the temperature is raised above that at which the oils are stable.

According to this view, the more important properties of a core oil are the specific strength of the coagulation product, the

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[3] R. H. Kienle and L. V. Adams (*The Mechanism of the Baking Processes of Oil, Varnishes and Enamels*—Research Laboratory, General Electric Co., publication) have found that polymerization is about one-fiftieth as rapid as oxidation at the usual baking temperatures.

[4] F. B. Leech, *Ind. and Eng. Chem.*, *18*, 316 (March, 1926).

time required to attain this specific strength throughout the core section, and the critical temperature beyond which the oil ceases to be stable.

Oils vary in respect to viscosity; some are thick and ropy, difficult to blend properly with sands unless thinned with diluents,—kerosene, benzol, turpentine or the like. Oils, and more particularly their coagulation products, vary in respect to moisture absorption and the effect of such moisture absorption upon core strength; this is of importance where considerable time elapses between the setting of cores in green sand molds and the final pouring off.

Finally, core oils are often compounded with rosin and the like; the additions may be valuable or they may be simply valueless adulterants.

It was the writer's intention to cover all of the points raised above, and several other points not as yet mentioned, perhaps not with absolute thoroughness but still thoroughly enough to make a fairly complete story. "Facts are necessary, and even a pack rat can collect a gallon of beans in a single night,"[5] but the collection of closely correlated facts is necessary to the development of a systematic story, and these are a matter of slowly deliberate accumulation when the collecting of them must be sandwiched in between other activities. The writer is therefore rather forced to choose between two alternatives;—the piecemeal publication of chapters which he hopes it will be possible to assemble to make a connected story, or a fairly complete story in some dim and distant future. After all, much in the way of correlated facts is unquestionably available if only it can be freely brought forward,—and unselfishly discussed.

The Materials Used

In Table 1 are listed some of the most frequently determined chemical properties of oils that have been used, or can be used, as core binders. The corresponding properties of the oils used in the writer's studies are given for comparison; except for the cot-

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[5] William Beebe (American Museum of Natural History); *"Jungle Days."*

tonseed oil the determined properties agree very well with the text book values, and the cottonseed oil used was a commercially pure crude oil.

The Hanus *iodine value* is a measure of the degree of unsaturation of an oil; it is more or less directly a measure of the number of double or triple linkages between carbon or hydro-carbon

Table 1

CHEMICAL PROPERTIES OF DRYING AND SEMI-DRYING OILS AND ROSIN*

	Melting Point ° C.	Specific Gravity 15° C.	Iodine Values	Saponification Value	Acid Value	Sayboldt Viscosity 25° C.
Vegetable Drying Oils						
Perilla	—4	.928–.931	188–206	189–191	...	...
Linseed (raw)	—15	.930–.935	171–204	190–195	...	...
" "	....	**.935**	**182**	**190**	**3.0**	**250**
Tung or	—18, +2	.941–.944	150–171	190–196	...	...
China Wood	....	**.940**	**179**	**201**	**5.3**	**1,050**
Soya Bean	—8, —10	.925–.927	130–143	191–194	...	...
" "	....	**.935**	**128**	**195**	**2.8**	**291**
Poppyseed	—18	.924–.927	134–143	190–198	...	...
Hempseed	—27	.925–.928	143–166	190–194	...	...
Walnut	—27	.928	142–150	186–190	...	...
Sunflower	—17	.924–.926	122–135	188–194	...	...
Vegetable Semi-drying Oils						
Corn	—10, —20	.922–.926	113–125	188–193	...	...
"	....	**.925**	**125**	**190**	**4.1**	**291**
Cottonseed	+3, +4	.922–.928	103–110	191–198	...	...
"	....	**.952**	**90.2**	**213**	**1.5**	**3,602**
Sesame	—3, —4	.922–.924	103–112	188–195	...	...
Ravison	....	...	101–122	...	...	...
Rapeseed	0	.913–.918	97–105	171–180	...	...
Beechnut	—17	.921–.923	111–120	191–195	...	...
Fish Oils: Semi-drying						
Menhaden	....	.922–.930	139–173	182–189	...	...
Sardine	....	...	161–193	...	...	...
Japan Sardine	....	...	100–187	...	...	...
Salmon	....	...	155–160	...	...	...
Herring	....	...	123–142	...	...	...
Collophony						
(Rosin)	100, 140	1.08	120–168	157–198	...	...

*From Industrial Organic Chemistry, Sadtler and Mates Chemiker Kalendar, 1915.
Data in bold face type relate to the materials used in the writer's studies.
Crude corn oil obtained through courtesy of the Corn Products Refining Co.
Other materials obtained from G. E. Co. Varnish Plant stocks.

radicles; since these multiple linkages afford the means of attachment between molecules in the process of coagulation, the iodine value is somewhat indicative of the readiness to coagulate.

The *saponification value* is a measure of the capacity of the oil to form potassium soaps; mineral oils do not form soaps, hence this determination is important in that it affords means of estimating mineral oil diluents or adulterants.

The *acid value* is a measure of the free acid present; such free acid may be mineral acid traceable to the refining processes, but it is more generally organic acids resulting from partial decomposition of the oil. The latter are responsible for the rancid odors frequently noticed in raw oils, but they do not contribute materially to the objectionable odors, or irritating fumes, encountered in the foundry when oil sand cores are destroyed by heat.

Sayboldt *viscosity* is an inverted measure of the fluidity of an oil. This varies greatly with temperature. Cottonseed oil and tung (China wood) oil are relatively viscous at ordinary core room temperatures; they are readily blended with sands in muller type mills, but they require diluents to thin them if they are to be well distributed through the sand by less intensive mixing methods.

Tung oil, particularly, behaves rather badly in cold storage. At temperatures only moderately below freezing, it separates quite readily into a rather fatty solid and a thin liquid; the addition of diluents, such as kerosene or benzol, does not prevent this separation. Soya and linseed oils have been kept outdoors in the coldest New York winters (−30 degrees Fahr.) without noticeable troubles of this kind.

The various sands used in testing core binders are described in Table 2. For most of the work with binders the writer used 50 mesh Ottawa banding sand,[6] since it is exceptionally clean and fine enough to yield cores with fair green strength.

Testing Methods

All sand mixtures were prepared in a small mill similar in principle to the mullers commonly used in the foundry[7]. The dry sand was weighed. The oil was measured in graduated glass cylinders until it was found that this introduced greater errors than inaccuracies in baking or mechanical testing. Much of this work was done in severely cold winter weather; irritating fumes from the core oven made it necessary to keep the laboratory windows open; the core oils were often cold and viscous and, in spite of allowing three minutes for drainage, as much as 15 per cent of

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[6] Obtained from the United States Silica Co., Chicago.

[7] Described by C. A. Hansen in A. F. A. Trans. XXXII, part 2, p. 59.

the oil volume was found to adhere to the glass cylinder walls. This error affects a considerable proportion of the results here reported—always in the sense that less oil was actually used than was reported used. Later, the oils were weighed into the sand mixer, and this is by all means to be recommended as a proper procedure in making test comparisons.

Water was added to yield about as wet mixtures as could readily be handled, all Ottawa sand mixtures containing 6.5 to 7.0 per cent moisture as molded. Contrary to the frequently expressed opinion that oil should be added to dry sand and well mixed before tempering, it was found to be immaterial whether the oil were added to dry sand or to moistened sand. The prepared mixtures were kept in sealed glass jars until molded, usually a matter of but few hours.

Table 2

Cumulative Screen Analyses of Core Sands

Sand No.	24	116	117	28	37	100A	93A
+10	.38	....	....	.1	.35	....	.16
20	6.75	1.11	.05	1.2	.81	0.00	.34
40	55.20	34.70	1.02	7.0	11.20	1.66	.75
70	93.20	84.40	67.93	54.4	44.78	14.52	1.60
140	99.20	99.50	97.86	98.3	82.82	71.70	10.65
270	99.80	99.94	99.46	99.6	94.62	94.54	42.49
—270	100.00	100.00	100.00	100.0	100.00	100.00	100.00
"Clay substance"	1.09	0.43	1.16	0.3	0.96	0.00	6.00
Rittinger Fineness Index*	4.04	3.70	3.20	3.11	2.84	2.32	1.06

No. 24—Dorchester Silica Sand, Dorchester, N. J. Charles Pettinos Co.
No. 116—Millville Silica Sand, Millville, N. J. N. J. Silica Sand Co.
No. 117—Millville Silica Sand, Millville, N. J. N. J. Silica Sand Co.
No. 28—Cedarville Silica Sand, Cedarville, N. J. George Pettinos Co.
No. 37—Albany Core Sand, Luzerne, N. Y. Corinth Sand Corp.
No. 100A—50 Mesh Banding Sand, Ottawa, Ill. U. S. Silica Co.
No. 93A—Albany Core Sand, Luzerne, N. Y. Corinth Sand Corp.

None of the above sands contain any appreciable amount of real clay. The material reported as "clay substance" is mainly fine sand with grain diameter less than 0.001 inches.

*See *The Grading of Molding Sands,* C. A. Hansen, A.F.A. Trans. vol. 34, p. 373(1927).

Cores 2 inches in diameter by 2 inches high, rammed with three blows of a 14 pound weight dropped 2 inches (heavy base A. F. A. permeability test ramming device), were used for green tensile strength, for green and dry compressive strength, and for green and dry permeability determinations. The green tensile strength was determined by a rather more sensitive modification

of the method proposed by A. A. Grubb.[8] The green compressive strength was determined by the method previously described by the writer[9] except that the core deformation was limited to 1½ per cent of the core height. The compressive strength of baked cores was determined by means of a standard Olsen testing machine of 1000, 5000, and 10,000 pounds load capacity. Green permeability was determined in the usual manner with the standard permeability equipment,[10] and the permeability of baked cores was determined in the same manner with cores baked in the tubes in which they were formed.

Standard A. S. T. M. cement briquet shaped cores, the neck section being one inch square, were hand rammed, variously baked, and tested in tension by means of an old beam type of Olsen cement testing machine.

All cores were baked in an electrically heated oven with inside dimensions 2 feet by 2 feet by 2 feet fitted with five perforated shelves. This oven is equipped with an automatic control panel actuated by means of a Bristol thermostat, and the temperatures are charted by means of a Bristol recording thermometer. Any temperature between 100 and 600 degrees Fahr. can be maintained constant indefinitely to within 10 degrees Fahr. Provision was made for supplying fresh air to the oven constantly, and for circulating the air within the oven to insure uniform temperature; both of these provisions were found unnecessary since without deliberate air supply the oven atmosphere was found to exceed 18 per cent oxygen when a full oven load of cores was absorbing oxygen at the maximum rate, and without deliberate air circulation cores were found to bake alike in all positions in the oven.

The evaporation of moisture from a full load of cores absorbed energy more rapidly than it could be supplied electrically with the resistor equipment used; this caused the oven temperature to drop; and the water vapor generated displaced a large fraction of the air within the oven so that the evaporation rate was less than is characteristic of fuel fired core ovens. The cores therefore required from half an hour to an hour and a half, depending upon the temperature range selected, to thoroughly dry.

[8] A. F. A. Trans. XXXII, part 2, p. 10, 1925.
[9] A. F. A. Trans. XXXII, part 2, p. 61, 1925.
[10] A. F. A. Trans. XXXI, pp. 708-721, 1924.

At this point the cores were barely strong enough to handle and they were then rearranged into groups so that a test batch could be removed with minimum disturbance of the oven temperature as the baking process progressed. In the records which follow, baking time is counted from the replacement of the approximately moisture free cores in the oven.

Cross bending tests for baked cores were made a regular routine practice for several months,—cores 1 inch by 2 inches in section, 8 inches in length, tested on supports 6 inches apart, but the method was abandoned for several reasons. Oil bonded cores develop strength by progressive oxidation of the cores from surface to center; a partially baked core consists essentially of a strong envelope enclosing a weak center. The cross bending strength is proportional to the moment of inertia of the strong envelope; the center elements of the core contribute little to the moment of inertia of the core section, and the weak center elements are not correctly rated as regards strength. On the other hand, both tensile and compressive strengths are practically proportional to the cross sectional area of the strong envelope, and the weak center elements are given more nearly true weight in the test results obtained. The writer was particularly interested in determining the rate of strength development throughout the core section, and both tensile and compressive strength tests serve this purpose much better than cross bending tests.

Cross bending strengths, converted to maximum fiber stress by the usual beam formulæ, are more or less hybrids resulting from the mating of tensile and compressive stresses. It happens that the tensile and compressive strengths of baked cores of the type here considered seem to bear a fairly constant ratio to one another, the tensile strength approximating a third to a quarter of the compressive strength; a constant ratio would indicate the cross bending test to be a rational one, but there is no *a priori* reason to believe that the ratio is definitely constant.

Maximum Strength versus Oil to Sand Ratio

With clean, clay free sands, the maximum strength developable in simple oil bonded cores is practically proportional to the amount of oil used in bonding unit weight of sand.

Table 3

Maximum Strength Versus Oil to Sand Ratio

c.c. Oil per Kg. Dry Sand	Hours in Oven: Drying	Hours in Oven: Baking	Tensile Strengths 7.5	Tensile Strengths 15	Tensile Strengths 25	Tensile Strengths 50	Compression Strengths 7.5	Compression Strengths 15	Compression Strengths 25	Compression Strengths 50
Tung Oil	2.0	+2	8.4	8.8	10.1	7.8	30.4	42.7	49.7	38.9
		4	10.2	10.9	15.3	11.8	33.4	46.3	61.0	49.8
		6	11.6	12.4	17.2	13.2	34.5	48.5	65.5	....
		8	12.4	13.4	17.6	14.0	35.0	49.5	68.0	52.0
		10	13.0	13.9	17.6	14.6	35.5	50.5	69.2	....
		20	13.0	14.0	17.6	15.0	33.0	53.6	70.0	52.0
		40	10.8	12.6	17.0	13.7	24.0	53.0	60.0	40.0
Linseed Oil	1.0	+2	4.0	5.6	5.0	7.8	40.2	37.3	35.6	33.8
		4	6.7	8.2	9.4	10.2	43.0	44.0	44.3	42.0
		6	10.7	12.6	13.1	12.3	44.0	48.0	50.5	47.0
		8	12.8	14.2	15.5	14.0	47.5	52.0	54.5	50.5
		10	13.7	14.2	15.5	14.0	49.0	53.5	56.5	53.0
		20	13.8	14.0	13.2	11.4	52.5	55.0	59.5	57.3
		40	12.0	13.0	12.2	10.4	50.3	51.3	58.5	52.7
Soya Bean Oil	1.5	+2	9.0	8.4	8.0	4.0	25.5	21.0	18.0	11.0
		4	11.6	10.9	10.2	7.6	48.0	43.5	37.5	25.5
		6	13.2	12.5	11.7	10.3	61.0	54.0	48.0	35.0
		8	14.4	13.7	13.2	12.2	69.0	62.0	54.5	41.5
		10	15.3	14.6	14.4	13.6	70.5	67.0	60.0	47.0
		20	16.2	16.0	15.5	14.5	70.9	70.5	70.0	56.0
		40	13.3	13.0	12.3	11.0	66.0	66.0	65.0	50.6
Crude Corn Oil:	1.8	+2	6.0	4.5	3.0	2.0	18.0	18.0	14.0	6.0
		4	10.2	8.8	7.4	5.3	29.0	26.0	25.0	17.0
		6	12.6	11.0	8.6	7.2	34.0	40.0	38.0	26.0
		10	15.5	13.8	12.4	9.0	43.0	50.0	46.0	32.0
		20	18.1	16.8	15.2	11.4	52.0	62.0	60.0	42.0
		40	19.2	17.7	16.0	12.4	60.0	70.0	70.0	51.0
Cottonseed Oil:	1.5	+3	4.6	3.7	3.0	1.9	....	....	....	....
		4	7.9	6.4	4.8	3.8	25.5	16.0	13.0	11.0
		6	11.2	9.4	7.4	6.1	32.0	21.0	19.4	17.1
		8	12.1	10.7	8.8	7.2	32.0	24.0	24.0	21.0
		10	12.6	11.4	9.7	8.0	32.5	26.0	27.0	24.0
		20	13.8	13.0	11.8	10.2	33.0	31.5	33.5	31.0
		40	14.7	14.1	13.2	11.4	34.0	36.0	38.2	33.8
Average of all highest strengths (5 oils)			15.38	15.20	15.56	13.46	50.58	57.02	61.54	50.12
Corresponding Lbs./sq. in.			116	228	389	673	379	855	1538	2506

Note—Maximum strength was probably not developed with corn oil, and was certainly not developed with cottonseed oil in the 40 hours to which the baking was carried.

50 mesh Ottawa banding sand.
80 c.c. water added for temper per kg. dry sand.
Raw oils added straight—without diluents.
Oven temperature 350°F.—range of temperature 340 to 355°F.
Strength reported—(Lbs./sq. in. of core section)/(c.c. oil used per kg. dry sand).
Bold face type indicates greatest strength of a series.

The simplest, and least merciful manner of showing this, without resort to graphs, is to divide the strengths developed by the amount of oil used; to support the introductory conclusion the ratio should be constant. This method is followed in Table 3 and in some of the following tables. Note particularly the averages of the maximum strengths for five different oils at the foot of Table 3.

Accordingly, it becomes unnecessary to test a given oil at several oil to sand ratios in order to properly rate the oil as a binder, and it is also proper to select an oil ratio which lends itself best to testing purposes instead of selecting the oil ratio from the standpoint of purely foundry requirements.

In our own foundries[11] it is our regular practice to bake cores over night at 350 to 375 degrees Fahr. Most of our oil sand cores contain auxiliary binders, patented dextrine and starch and the like, and none of these binders is stable at temperatures above 375 degrees Fahr. In Table 3 it will be noted that cores bonded with linseed, tung, and soya bean oils attained maximum strength within 40 hours; cores bonded with corn oil barely attained maximum strength in 40 hours, and cores bonded with cottonseed oil did not attain maximum strength in 40 hours.

Maximum Strength versus Baking Temperature

At temperatures below which oils are not destroyed by destructive distillation, the maximum strengths developable in simple oil bonded cores are virtually independent of the baking temperature. The time required to develop maximum strength decreases very rapidly as the baking temperature increases.

The oils are certainly not stable at temperatures above 350 degrees Fahr., as evidenced by the fact that all of the cores deteriorate in strength if baked too long. Oil paint films deteriorate when aged for long periods at room temperature, and it is highly probable that the instability of the strength of coagulated oil films is a characteristic of oils at all temperatures. The rate of deterioration of strength also increases very rapidly as the baking temperature increases.

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[11] General Electric Co., Schenectady foundries.

The data given in Table 4 are subject to the above mentioned errors in measuring oil volumes, and they do not support the introductory conclusion in an entirely satisfactory manner. Cross

Table 4

Maximum Strength Versus Baking Temperatures

Hours in oven: Drying	Hours in oven: Baking	°F.	Oil Used: Tensile Strengths: Tung	Linseed	Soya	Corn	Cotton	Compressive Strengths: Tung	Linseed	Soya	Corn	Cotton
0.75	+ 1.0	440	Not determined					66.2	44.6	20.0	24.2	9.5
	1.5							73.8	57.3	38.2	34.4	22.9
	2.0							80.2	64.9	57.3	43.3	30.5
	2.5							85.2	**66.2**	68.7	50.9	38.2
	3.0							**86.6**	**66.2**	72.6	54.7	43.3
	4.0							**86.6**	63.6	**73.8**	**58.6**	50.9
	6.0							73.8	59.6	61.2	53.5	**57.3**
	22.0							38.2	35.5	40.7	21.7	42.1
1.5	+ 1.0	400	Not determined					90.0	79.5	56.2	....	....
	5.3							**98.1**	**86.7**	**70.4**	....	....
	17.0							72.0	68.0	67.0	....	....
1.5	+ 2	350	10.1	5.0	8.0	3.0	...	49.7	35.6	18.0	**14.0**	....
	4		15.3	9.4	10.2	7.4	4.8	61.0	44.3	37.5	25.0	13.0
	6		17.2	13.1	11.7	8.6	7.4	65.5	50.5	48.0	38.0	19.4
	10		**17.6**	**15.5**	14.4	12.4	9.7	69.2	56.5	60.0	46.0	27.0
	20		17.6...	13.2	**15.5**	15.2	11.8	**70.0**	**59.5**	**70.0**	60.0	33.5
	40		17.0	12.2	12.3	**16.0**	**13.2**	60.0	58.5	65.0	**70.0**	**38.2**
2.0	+24	300	16.5	19.6	7.9	....	....	75.2	72.3	46.8	....	....
	68		17.0	**26.1**	17.4	....	....	80.0	**86.5**	60.3	....	....
	92		**20.4**	22.7	**21.7**	....	....	**94.2**	82.0	82.5	....	....
	116		....	....	....	....	....	89.6	82.7	**85.6**	....	....
2.0	+10	250	1.6	5.6	1.0	....	....	7.6	10.0	4.5	....	....
	22		8.3	9.3	1.6	....	....	10.4	16.9	5.8	....	....
	45		6.1	8.0	2.2	....	....	10.9	22.5	7.8	....	....
	71		11.2	10.1	2.8	....	....	14.5	31.2	11.3	....	....
	115		12.4	14.4	3.5	....	....	17.0	32.6	13.0	....	....

Estimated time required to attain maximum strength: Hours at temperature indicated exclusive of time required to rid the cores of moisture.

°F.	Tensile: Tung	Linseed	Soya	Corn	Cotton	Compressive: Tung	Linseed	Soya	Corn	Cotton
500°F.	....	....	....	....	....	0.8	0.7	0.85	1.0	1.2
450	....	....	....	....	....	2.3	1.9	2.6	3.0	4.2
400	....	....	....	....	....	7.1	5.8	9.0	11.0	17.0
350	10	10	15	30	50	25.0	18.0	34.0	40.0	70.0
300	....	....	....	....	....	100.0	72.0	150	185	360
250	....	....	....	....	....	500	340	840	1100	2300
200	....	....	....	....	....	...	1900	...	....	......

Notes:

50 mesh Ottawa banding sand.
25 c.c. oil per kg. dry sand (measured volumes).
80 c.c. water per kg. sand added to temper.
Oven temperatures as indicated.
Strengths reported: Lb. per sq. in. core section/c.c. oil per kg. sand.
Bold face type indicates maximum strength of a series.

averages for tung, linseed, and soya bean oils bear out the conclusion in better degree; corollary experiments with weighed oil quantities confirm it so far as they go, and wholly independent observations by Kienle and Adams,[12] on the behavior of baked

[12] See footnote 3.

oil films on sheet metal, leave little doubt in the writer's opinion that the conclusion is accurate.

Kienle and Adams have shown that the time required to attain maximum strength in oil films (on sheet metal surfaces) is simply related to the baking temperature;

$$\text{Log K} = \frac{A}{T} - B$$

where K is the time required, A and B are constants for any given oil, and T is the absolute temperature referred to -273 degrees Cent. The time required to develop maximum strength in oil bonded cores was found to agree remarkably well with this formula, and it was used in estimating the time required to develop maximum strengths at various baking temperatures with the results given at the foot of Table 4.

A somewhat idealized plot of the relations between strength and baking time for linseed oil cores is shown in Fig. 1.

The time required to bake an oil sand ore increases with the size of the core. Certain very pretty theories concerning the rate of strength development seemed to be agreeably checked by experiment, but these theories required that the time necessary to attain maximum strength should vary with the square of the diameter of cylindrical cores, and that it should vary inversely with the permeability of the cores. When confirmation was sought by baking cores varying from 1½ to 4 inches in diameter, the height being 1½ times the diameter, it was found that the time actually required increases rather less rapidly than the diameter. With cores ranging from 10 to 250 in permeability, the time required to develop maximum strength was found to vary but slightly with the permeability.

Baking temperature is certainly the major variable; the futility of attempting to develop maximum strength in any practicable time period at temperatures below 350 degrees Fahr. is evident, and the need for extreme care to avoid overbaking at higher temperatures is also evident.

Twelve wholly independent series of tests place tung oil, linseed oil, and soya bean oil in the order 100 (per cent), 98, and 90 as regards maximum strength developable; tung oil and lin-

seed oil are certainly equivalent and soya bean oil lags but little behind. Too few tests to make the conclusions entirely acceptable place corn oil and cottonseed oil in the order of 78 and 67 on the same strength scale. The relative values may, and probably will, vary with other lots of oil, but tung and linseed oils have been used interchangeably in our own foundries for several years and there is little doubt that they, at least, are generally equivalent.

Within the baking temperature limitations imposed by the use of auxiliary binders, starches, sugars, gums and the like, linseed and tung oils are practically equivalent as regards baking

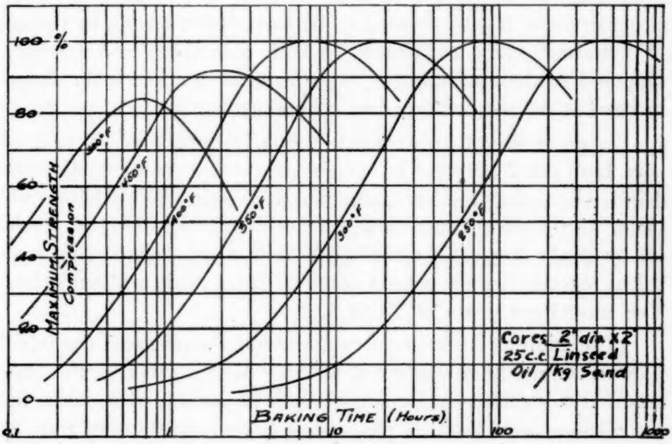

FIG. 1—THE EFFECTS OF BAKING TIME AND TEMPERATURES ON THE STRENGTH OF LINSEED OIL CORES

time; soya bean oil is very appreciably slower to bake; corn oil is decidedly slow to bake; and cottonseed oil is impossibly slow.

The usual foundry method of judging whether an oil sand core is properly baked is to test sharp core edges for strength or hardness. This method failed completely to distinguish between cores baked to maximum strength and cores baked to 10 per cent of maximum strength. The latter possessed hard strong surface shells about an eighth of an inch in thickness, and the core centers were soft, and even greasy. Some evidence was collected tending

to show that castings tear more easily over weak, poorly baked cores than they do over strong, properly baked cores. This is not impossible, nor even improbable; the weak core is capable of developing strength at the critically wrong period in its life history, i. e., after the casting has taken shape around it; the properly baked core, on the other hand, falls off in strength very rapidly as heat penetrates from the hot casting.

The Effect of Driers Upon Oils

Of the three oils which are comparable in respect to strength, viz., tung, linseed and soya bean oils, the last is generally least expensive and it also seemed to be least objectionable in respect to irritating odors and fumes in both core room and foundry. Opposed to these advantages, soya bean oil is appreciably slower to bake at the temperatures we commonly use.

In an endeavor to accelerate the development of strength of soya bean oil, 2 per cent by weight of various commercially used driers, viz., cobalt linoleate, manganese resinate, and calcium resinate, were added to successive batches of oil, and dissolved in the oil by gentle heating. Cores made with these treated oils were baked together with a control batch of cores made without driers. The results are given in Table 5.

The addition of driers very appreciably accelerated the initial rate of strength development at 350 degrees Fahr.; the time required to develop maximum strength is possibly reduced to the point where soya bean oil plus driers is comparable with tung or linseed oil without driers. The driers used are commonly added in processing linseed oil; they are not necessarily most appropriate for use with soya bean oil; the field to be covered in this way is an almost endless one.

Two years ago a considerable quantity of data was collected in studying linseed and tung oils, both as raw oils, and as blended with various driers in our varnish plant. These data showed little or no effect upon cross bending strengths traceable to the driers, only a slight acceleration of the baking rate at 350 degrees Fahr., and a fairly consistent increase in the tendency to foul core boxes traceable to driers.

It is almost certain that driers can affect only the rate of strength development and, incidentally, they can affect the rate of strength deterioration on overbaking to the same degree, and in the same direction. The acceleration of the oxidation rate persists at all temperatures; the tendency to foul core boxes is measured by the oxidation rate at room temperature; and the acceleration persists into the destructive stage of oxidation.

Table 5

Soya Bean Oil Plus Driers

Hours in Oven: Drying	Hours in Oven: Baking	Compressive strength lbs. per sq. in./c.c. oil per kg. sand: A	B	C	D	Tensile strength lbs. per sq. in./c.c. oil per kg. sand: A	B	C	D
2.25	+ 3.0	25.6	42.0	43.4	41.0	8.3	8.2	9.3	8.5
	+ 4.5	38.0	46.8	50.6	50.8	10.0	(8.1)	10.9	10.1
	+ 7.75	57.8	62.4	59.2	66.8	13.3	12.7	15.0	15.6
	+11.75	65.6	74.8	76.0	75.5	16.7	17.7	16.3	16.3
	+20.0	78.0	74.0	66.6	75.0	20.3	21.5	20.8	21.1

Notes:
50 mesh Ottawa banding sand.
80 c.c. water added for temper per kg. dry sand.
25 c.c. soya bean oil (by weight) per kg. dry sand.

Driers used:
A—None.
B—2% (oil weight basis) cobalt linoleate.
C—2% (oil weight basis) manganese resinate.
D—2% (oil weight basis) calcium resinate.

Oven temperature 350°F.: Temperature range 340-360°F.
Bold face type figures represent greatest strength developed in a series.

The Effect of Diluents Upon Core Oils

Linseed oil, tung oil, and soya bean oil, raw, and variously boiled in our varnish plant, were diluted with equal volumes of gasoline, kerosene, light oil, spindle oil, benzol, and turpentine. The immediate effect of dilution with any of these is to reduce the viscosity of the basic core oil. Light oil and spindle oil are bland; they possess lubricating qualities, and they do not seriously affect the smoothness and unctuousness of the basic core oil; they are commercial favorites for this reason. The other diluents all yield harsh, sharp mixtures, obviously "cut" and thus obviously adulterated, and the core maker looks askance at them.

None of these diluents appreciably affected the time required to develop maximum core strength at 350 degrees Fahr. The mineral oils did not measurably affect the maximum strengths developable per unit weight of basic vegetable core oil; they are

diluents pure and simple, and they serve no purpose when used with vegetable oils of normally low viscosity. Benzol and turpentine seemed consistently to decrease the maximum strengths developable, and they are believed to be definitely harmful.

All of the basic core oils above mentioned become progressively more viscous when they are heated for long periods in the varnish plant kettles. Finally they become so thickened that it is practically impossible to blend them properly with sand unless they are first thinned with a diluent. In this manner, it is relatively easy to prepare an oil mixture which will have the smoothness and the "body" of a pure vegetable oil but with only a fraction of the bonding value of the latter.

The Effect of Boiling Linseed Oil

In the process of making varnish oils, the raw linseed oil is heated for rather long periods in large open kettles, the final temperatures being on the order of 600 degrees Fahr. The final product is extremely viscous.

During one such operation of boiling linseed oil, without

Table 6

Effects of Boiling Upon Core Oils

Baking temperature: °C		180	180	180	180	230	290
°F		356	356	356	356	445	554
Hours baked (total)		4	8	16	60	16	16
Linseed oil kerosene	Sayboldt viscosity 25°C of mixture	Compression strengths in lbs. per sq. in. 12.5 c.c. linseed oil per kg. dry sand					
Raw oil	58	...	...	645	630	...	..
Boiled 6 hrs.	79	470	530	705	710	49	38
12 hrs.	118	395	770	740	730	74	35
18 hrs.	125	235	530	680	670	95	21
24 hrs.	170	270	510	700	710	108	35
30 hrs.	187	325	570	705	680	140	22
36 hrs.	227	220	520	680	680	190	16
40 hrs.	2330	290	690	660	...	268	16

Variously "boiled" linseed oil. (Measured volumes.)
Cedarville silica sand.

other additions, in our varnish plant, samples were removed at 6 hour intervals throughout the 40 hour process campaign. Each sample was diluted with its own volume of kerosene and mixed with Cedarville silica sand (see Table 2). Cores made with these mixtures were tested with results shown in Table 6. These data were obtained two years ago, with less elaborate control than char-

acterizes later work, but the strengths attained agree almost exactly with recently obtained strengths of linseed oil cores made with the same sand. There is little to indicate that the maximum strength is affected by the heat treatment of the oil, or that the baking time is materially affected. The increase in viscosity of the linseed oil as the boiling progresses is reflected in the viscosities of the diluted oils. A strangely consistent relation was found between the strengths retained after 16 hours of baking at 230 degrees Cent. (about 450 degrees Fahr.), which would indicate that the boiling process increased the stability of the oil in the 350 to 450 degrees Fahr. range. This should connote a slower baking rate for the boiled oils in order to fit in with that which has preceded, but such a conclusion would be rather contrary to generally accepted views regarding oils.

Both linseed and tung oils were similarly boiled with various driers. The driers did not appreciably affect the results obtained.

It does not appear that the boiling of oils, either with or without driers, is justified by any gain in value of the products as core binders.

Table 7

Oils and Sulphur

Hours in Baking Oven: Drying	Hours in Baking Oven: Baking	Strengths, Tung Oil			Strengths, Linseed Oil			Strengths, Soya Bean Oil		
3	+ 2	64	62	56	53	43	48	20	16	14
	4	78	79	69	65	70	73	41	30	32
	6	84	86	75	76	82	84	53	42	48
	10	88	92	78	85	91	92	66	62	72
	20	90	95	81	89	96	93	77	86	88
Per cent Sulfur— Oil Wt. Basis		0	3	300	0	3	300	0	3	300

Notes:
50 mesh Ottawa banding sand.
25 c.c. oil (net weight) per kg. dry sand.
80 c.c. water per kg. sand.
Baking—350°F.
Strength reported—Lbs. per sq. in./c.c. oil per kg. sand. (Compression.)

The Effect of Sulphur on Core Oils

Various dense molded insulations are regularly made by hydraulically compressing mixtures of asbestos fiber and the like with linseed oil. Usually about three per cent of sulphur is added, based upon the oil weight, and the shapes are cured, or vulcanized by baking.

Comparison cores were made with linseed oil, tung oil, and

soya bean oil to which sulphur was added to the extent of 0, 3, and 300 per cent, based upon oil weight. The data for the zero sulphur series were taken from Table 3; the oil volume being subject to errors previously mentioned; the oils to which sulphur was added were weighed. The results of the comparison, interpolated to bring them all to a common time basis, are shown in Table 7.

Sulphur neither affects the baking rate nor the maximum strength appreciably. The cores were baked in the usual manner,

Table 8

Tung Oil, Rosin, Kerosene

Mixtures used:	A	B	C	D	E	F	G
Tung oil—liters	none	2	1	1	1	1	1
Kerosene—liters	below	0	1	1	1	1	1
Rosin—grams	400	0	0	200	400	700	1000
Total liters mix	2.00	2.00	2.00	2.19	2.39	2.65	2.84
Density—20°C	....	0.940	0.870	0.888	0.905	0.921	0.951
Viscosity—25°C	....	1050	81	150	243	700	1200
c.c. Oil mixture per kg. dry sand	Compressive strengths—Lbs. per sq. in.						
12.5 (note)	11.6	310	260	360	430	480	500
25.0	14.5	640	620	750	830	920	1000
50.0	54.7	1290	1260	1600	1740	1850	1950
	Corresponding c.c. base oil per kg. dry sand						
12.5	0	6.25	6.25	5.70	5.23	4.71	4.40
25.0	0	12.50	12.50	11.40	10.46	9.42	8.80
50.0	0	25.00	25.00	22.80	20.90	18.85	17.60
	Corresponding grams rosin per kg. dry sand						
12.5	2.5	0.0	0.0	1.14	2.09	3.30	4.40
25.0	5.0	0.0	0.0	2.28	4.18	6.60	8.80
50.0	10.0	0.0	0.0	4.56	8.36	13.20	17.60
	Deducting from the total strength that contributed by the oil, the residual strength due to rosin for each gram rosin per kg. sand is as follows:						
12.5	4.6	...	...	68	83	75	64
25.0	2.9	...	...	72	70	67	62
50.0	5.5	...	...	92	79	66	59

Note—Half volumes of the undiluted oil (column B) were added, i. e., the actual volumes of vegetable oil were the same for columns B and C.
Cedarville silica sand.
Cores baked at 180°C (ca. 350°F.).
Baking period—20 hours.

with free access of oxygen, and it is probable that the oxidation process of coagulating the oils is more rapid than the sulphur bonding process at the temperatures used. There were no odors of sulphur dioxide so it is certain that the sulphur was not merely burned out.

While it is of interest to find some method whereby core oils

can be made to develop strength more rapidly, it is rather fortunate that the sulphur method does not offer promise in this direction. Bad as core oils are in respect to irritating fumes given off in the core ovens and in the foundry, the fumes given off by the oil-sulphur mixtures are infinitely worse.

According to Kienle and Adams, the irritating fumes given off by the normal oils owe their disagreeable nature to acrolein (glycerine aldehyde); the fumes from the oil-sulphur mixtures probably contain mercaptans as well, the latter being sulphur compounds of most disagreeable odor.

The Effect of Rosin on Core Oils

Rosin is very commonly found in commercial core oils in amounts ranging from 10 to 30 per cent by weight. Generally the amount of inert mineral diluent found in commercial oils increases with the rosin content. The immediate effect of adding rosin to pure vegetable core oils is to enormously increase the viscosity. This is reflected in the viscosities of the diluted oils in Table 8. Relatively little rosin can be added to pure oils before it becomes necessary to add diluents in order to thin the compound oil so that it will blend properly with sands.

Two years ago a fairly lengthy series of tests was made with linseed oil and with tung oil variously compounded with rosin and diluents. The two oils yielded almost identical results, of which those given in Table 8 are thoroughly typical. The data given in column B were obtained recently and they are added as a check upon column C.

There is no *a priori* reason to expect that the strengths conferred by multiple binders will be additive, but the fact remains that this is found to be practically true for mixtures of oil with starches, dextrins, sugars, gums, and with binders of the glutrin-goulac type. It is not true for mixtures of oils and clays, or for mixtures of oils and black pitches. On the assumption that it is true for mixtures of oils and rosin, the rosin in the oil-rosin mixtures in Table 8 contributed rather more strength per unit of binder weight than did the oil. Rosin is materially less expensive than oil, and rather less expensive than the cereal type binders. Unlike the latter, rosin is but slightly affected by moisture. On

the whole, it seemed that the use of rosin was both beneficial and economical.

Recently, tests were made with tung oil, with linseed oil, and with soya bean oil, to each of which 20 per cent by weight of rosin was added and dissolved by gentle heating. Kerosene was added as diluent. The results of the more recent tests agree fairly well with earlier test results—(see Table 9).

In this table, the comparison data for straight oil cores are derived by averaging several sets of recently determined results;

Table 9

Oils and Rosin

			Soya Bean Oil		
c.c. Oil per kg. sand (net weight)		14.08	14.08	28.80	28.80
Rosin — per cent of oil weight		0	20	0	20
Hours in Oven					
Drying	Baking	Compressive strengths—lbs. per sq. in.			
1.5	+ 2.0	280	1400	576	1950
	4.0	576	1480	1080	2200
	8.0	705	1550	1440	2500
	15.0	905	1590	1860	2910
	18.0	1070	1590	2190	2900
			Linseed Oil		
c.c. Oil per kg. sand (net weight)		14.18	14.18	28.60	28.60
Rosin — per cent of oil weight		0	20	0	20
Hours in Oven					
Drying	Baking	Compressive strengths—lbs. per sq. in.			
1.5	+ 2.0	750	970	1520	1650
	4.0	920	1380	1860	2500
	8.0	1060	1560	2340	2930
	15.0	1250	1720	2520	3280
	18.0	1260	1685	2550	3260
			Tung Oil		
c.c. Oil per kg. sand (net weight)		13.70	13.70	26.45	26.45
Rosin — per cent of oil weight		0	20	0	20
Hours in Oven					
Drying	Baking	Compressive strengths—lbs. per sq. in.			
1.5	2.0	875	1370	1840	2710
	4.0	1070	1580	2250	3000
	8.0	1185	1750	2490	3110
	15.0	1225	1830	2580	3100
	18.0	1235	1845	2590	3010

Note—Tensile strength tests yielded the same proportionate results.
50 mesh Ottawa banding sand.
80 c.c. water added per kg. dry sand.
Baking temperature 350°F.

the six lots of rosin oil mixture cores were baked together. Again, the rosin appears to have contributed its full weight share to the maximum strength developed, and the rate of strength development appears to have been enormously accelerated by the rosin in all cases.

The cores made with rosin alone (Table 8) developed but little strength. It is possible that the vapor pressure of the rosin

is reduced by dissolving it in oil, thus increasing its stability at 350 degrees Fahr. This possibility was not further investigated. Rosin alone, dissolved in kerosene, concentrates at the core surfaces during the baking process, leading to cores with hard surfaces and soft centers. In this respect it behaves like all water soluble binders except such, aluminum chloride for example, as depend upon hydrolysis for the development of strength. If a similar concentration occurred with the rosin-oil mixtures, the effect was obscured by the strength due to oil. Rosin is said to yield cores which are soft when removed from the hot oven and which develop strength only when cooled below the rosin melting point. This did not appear true for any of the rosin-oil cores here considered.

Table 10

Permeability of Oil Cores

c.c. Oil added per kg. sand—	7.5	15.0	25.0	50.0
	Permeabiliy—A. F. A. Units			
Tung oil	49	49	44	44
Linseed oil	49	49	49	38
Soya bean oil	52	49	44	31
Cottonseed oil	52	55	52	47
Averages—	50.5	50.5	47.2	37.5

Comparison Permeabilities—Cereal Binder Types

Grams dry binder per kg. sand—	5	10	20
	Permeability—A. F. A. Units		
Wheat flour	49	49	49
Rye flour	49	47	52
K-B	58	55	29
Ajax	49	49	40
Kordek	58	52	44
Argo starch	58	49	44
Argo starch-gelatinized	58	47	38
Mogul	49	44	33
Averages—	53.5	49.0	41.1

Notes:
50 mesh Ottawa banding sand.
Baking—20 hrs. at 350°F.

On the whole, the use of rosin in core oils is not unwarranted, and rosin can certainly not be considered to be merely an adulterant. As previously stated, however, the use of any appreciable amount of rosin involves the necessity of adding inert diluents to control the viscosity of the compounded oil, with consequent reduction in the binding value of unit volume of compound. The writer has not tested a great many reputable commercial core oils and he does not feel free to generalize in regard to them, but he has found no commercial oil which developed as great strength

as pure linseed or pure tung oil when the comparison is based upon oil volumes. Several commercial oils have been found which develop as great strength per unit of cost as pure linseed and pure tung oils; the best of these contains approximately 20 per cent rosin in linseed oil, the mixture diluted with about half its volume of mineral oil. The mixture is, on the whole, rather more nearly fool proof than pure linseed oil.

The Effect of Oil on Core Permeability

The permeability of cores is determined primarily by the grain size characteristics of the sand used in the core mixtures, and secondarily by the moisture in the sand mixtures and the amount of ramming done in forming the cores. The oil used as binder affects the permeability only to a very minor extent and, weight for weight, the oils have approximately the same effect upon the permeability of cores as have any of the other binders commonly used.

Comparisons are made in Table 10 between cores, made in the same way and from sand mixtures molded in the same moisture range, with oils as binders and with other commonly used binders.

The Effect of Moisture on Oil Sand Cores

Oils owe their peculiar merit as core binders primarily to the fact that the strength of oil bonded cores is but slightly affected by moisture. In this respect, the oils are superior to all other binders commonly used in the foundry with the exception of the coal tar or petroleum tar pitches; the latter, alone, are entirely unaffected by exposure to a saturated atmosphere and they can, in fact, be immersed in water without measurable deterioration in strength.

Oil bonded cores do deteriorate in strength when exposed for any length of time in a saturated atmosphere, as, for instance, when cores are kept in closed green sand molds for several hours before pouring off. Cores made with each of the five oils here considered were baked to maximum strength at 350 degrees Fahr. The baked cores were tested for strength while fresh and dry from the oven, and after exposures of a day, and a week, in a saturated atmosphere. The saturated atmosphere was provided in an aging chamber for cement briquettes, saturation being insured by a con-

tinuous water spray, the cores being shielded from direct contact with the spray. The results obtained are given in Table 11; these results are in almost exact agreement with similar ones obtained some years ago. The actual amount of moisture absorbed is extremely small, but its effect upon the strength of the cores is very appreciable.

Weight for weight, the various starches, dextrins, sugars, gums, etc., used in the foundry are comparable with the oils in respect to dry core strengths developable, but on exposure to a

Table 11

Moisture and Oil Sand Cores

Oil—	Tung	Linseed	Soya	Corn	Cotton
c c. Oil per kg. sand (wt.)	13.60	14.18	13.96	13.73	13.63
Moisture in sand as molded, per cent	8.2	8.2	8.1	8.1	8.1
Hours baked—350°F	20	20	30	48	67
	Compressive strengths—lbs. per sq. in.				
Freshly baked cores	1230	1280	1115	1075	880
Exposed to saturated atmosphere at room temp. 1 day (24 hrs.)	970	820	950	960	800
1 week (168 hrs.)	980	830	830	820	740
	Moisture absorbed from saturated atmosphere				
1 day exposure:					
Weight moist core	170.740	169.000	168.336	167.715	167.294
Weight dry core	170.363	168.921	168.330	167.665	167.262
Moisture absorbed	0.377 (?)	0.079	0.006	0.050	0.032
1 week exposure::					
Weight moist core	168.568	170.224	167.522	168.048	166.852
Weight dry core	168.557	170.162	167.458	167.995	166.797
Moisture absorbed	0.011	0.062	0.064	0.053	0.055

Note:
50 mesh Ottawa banding sand.

saturated atmosphere the strengths of the cores fall away almost to the vanishing point. The use of oils in conjunction with these other binders does not in the least prevent the absorption of moisture, and the strength of the composite binder core, after exposure to a saturated atmosphere, is practically that due to oil alone.

The Effect of Clay Upon Core Oil Requirements

Sharp, clay free sands, sufficiently coarse to yield properly permeable cores, lead to sand mixtures of relatively low green strength when merely oil and water are added to them. Clay bonded molding sands are frequently added to the sharp core sands in order to

improve the green strength, and this practice is commonly known to lead to greatly increased oil consumption. The usual explanation, and it is as good as any, is that the oil is absorbed upon the clay.

Ottawa sand was variously mixed with an excellent bonding clay. The clay mixtures were variously bonded with linseed oil, and with linseed oil plus 20 per cent rosin. The compressive strengths of these various mixtures are compared in Table 12. The addition of very little true clay, directly or as clay bonded molding sand, can easily double and triple the oil required to yield cores of practicable strength.

Rosin does not appear to be selectively absorbed, in so far

Table 12

Oils; Oils Plus Clay; Oils Plus Rosin Plus Clay

	Sands bonded with clay only			
Per cent clay (sand weight basis)	0	2	5	16
Moisture—Per cent in sand as molded		Strength		
4	0	30	70	100
5	0	46	92	122
6	0	60	104	137
7	0	68	115	150
8	0	75	123	162
9	0	80	130	172

	Sands bonded with clay plus oil			*Sands bonded with clay, rosin and oil*		
Per cent clay (sand basis)	0	2	5	0	2	5
Moisture per cent; as molded	7.6	7.6	7.6	7.6	7.8	8.1
c.c. Raw linseed oil per kg. sand		Strength			Strength	
0	0	72	120	0	73	124
2.5	220	105	135	280	110	130
5.0	440	155	200	560	190	270
10.0	880	300	350	1120	370	...
20.0	1760	650	690	2240	1300	...

Note—All above data were interpolated from smoothed plots in order to bring them to a common basis of oil to sand ratio.
Tensile tests show the same proportionate results.
50 mesh Ottawa banding sand.
Air floated fire clay (Queens Run Refractories Co., Lock Haven, Pa.).
Baking—20 hours at 350°F.
Raw linseed oil—20 per cent by weight (oil basis) of rosin in oil-rosin mixtures.
Strengths reported—Lbs. per sq. in. compression.
All materials weighed.

as it does not appear to appreciably alter the strengths obtained with moderate oil to sand ratios.

A. A. Grubb has shown[13] the effectiveness of using fine silica flour as a substitute for molding sands for increasing the strength

[13] A. A. Grubb, *Selection and Blending of Core Sands,* Trans. A. F. A., vol. 3[illegible], pp. 808-814, 1926.

of core mixtures. The use of silica flour does not seriously increase the oil requirement but it does rather seriously impair the permeability of the cores. It has seemed to the writer that a still better practice is to select as fine a sand as may be permissible in respect to permeability and to use this simple sand as the basis of the entire core sand mixture.

Table 13

Grain Size of Core Sands

	*Natural sands**	"Clay Substance" %	Rittinger Fineness	Temper Moisture %	Baked Cores Density Gm/c.c.	Baked Cores Permeability	Strengths† Tensile	Strengths† Compression
No. 24	Dorchester	1.09	4.04	5.1	1.662	235	14.4	50.2
No. 116	Millville	0.43	3.70	4.4	1.633	235	17.0	69.5
No. 117	Millville	1.16	3.20	5.5	1.521	138	15.6	58.5
No. 28	Cedarville	0.30	3.11	5.4	1.490	146	15.2	52.4
No. 87	Luzerne	0.96	2.84	6.5	1.621	65	15.4	57.8
No. 100A	Ottawa	0.00	2.32	7.0	1.571	49	22.5	87.0
No. 93A	Luzerne	6.00	1.06	9.3	1.526	9.4	6.6	30.5
	Sand plus clay							
	Ottawa	0.00	2.32	7.0	.....	49	22.5	87.0
	Ottawa	2.00	2.32	7.6	.....	...	10.1	26.0
	Ottawa	5.00	2.32	7.6	.....	29	8.7	27.6

*For screen analysis see table 2.
†Strength reported—Lbs. per sq. in./c.c. oil added per kg. sand.
25 c.c. linseed oil per kg. dry sand (net weights).
Temper—All sands tempered to approximately the same apparent moisture.
Baking—20 hours at 350°F.

Grain Size of Core Sands Versus Oil Requirement

A few years ago, the writer made a series of tests with four fairly clean core sands used in our own foundries. These tests indicated very consistently that the oil required to produce a given practicable core strength varied inversely, but linearly, with the Rittinger Fineness Index[14]. This fitted in very well with the known facts that silty sands, and clay containing sands, required an excessive amount of oil; it was unnecessary to bring in adsorption to account for the oil consumption since fineness alone was sufficient to account for the oil required. The writer freely contributed this information in discussions with various friends interested in foundry sands.

It is a pertinent argument in favor of never repeating a series of experiments that has appeared to yield conclusive results. The

[14] C. A. Hansen, *The Grading of Molding Sand,* advance preprint No. 26-3, 1926, American Foundrymen's Association. See also Trans. A. F. A., vol. 34, p. 373 (1927).

data conveyed in Table 13 are considered to cover this field only in so far as they entirely disprove the introductory paragraph.

The Green Strength of Core Sands

In an earlier paper,[15] the writer referred to certain peculiarities in the green strength of sand mixtures. These peculiarities become especially evident in core sand mixtures generally.

Simple oil sand mixtures are notably weak in respect to green

Table 14

Green Strengths of Core Sands

c.c. Oil/kg. sand	0	7.5	15	25	50	0	7.5	15	25	50
	Green tensile strength					Green compression strength				
Tung oil	318	185	230	235	242	2330	1910	1910	1850	1830
Linseed oil	318	195	208	215	280	2330	1870	1970	2060	2030
Soya bean oil	318	200	205	225	266	2330	1840	1820	1890	1880
Corn oil	298	153	150	157	200	2215	1580	1600	1520	1510
Cotton seed oil	318	203	234	227	234	2330	(1550)	1550	1550	1850
Averages	314	187	205	212	238	2304	1750	1770	1774	1820

Comparison Cores with non-oil binders:

Grams Dry Binder/Kg sand		0	5	10	20	0	5	10	20
	Moisture	Green tensile strength				Green compressive strength			
Gum Tragacanth	8.6	326	230	250	252	2400	1530	1655	1540
Gum Arabic	7.9	323	271	308	372	2420	1730	2030	2295
Wheat flour	7.4	320	243	249	203	2340	1805	1790	1765
Rye flour	8.5	325	237	242	170	2400	1895	1820	1430
Argo Starch	8.7	330	215	183	164	2375	2180	2045	1835
Argo starch Gelatinized	7.7	320	272	332	322	2380	2210	2480	2585
Mogul	8.8	330	250	258	247	2375	1880	1865	2090
Falkobond	8.6	326	263	266	272	2400	1835	1955	1640
Ceres	8.5	325	254	266	302	2400	1700	1805	2075
K-B	8.0	323	252	265	278	2420	1780	1780	1940
Ajax	7.8	320	255	271	292	2380	1745	1760	1985
Kordek	8.6	326	271	253	258	2400	2000	2015	2075
Canary Dextrin	4.5	285	215	206	165	2050	1497	1495	1505
No. 8 Smokeless	8.2	323	307	287	284	2420	2400	2510	2495
Averages		323	253	260	256	2380	1870	1930	1950

Note—The "Moisture" reported is for the 0 and 10 columns. The moistures for the other columns varied slightly but not radically.

50 mesh Ottawa Banding Sand.

Tensile strength—Grubb method—Grams breaking load for 2" dia. core.

Compressive strength—Hansen method—Grams breaking load for 2" dia. core.

All core sands tempered to approximately same apparent moisture.

Strengths reported for sands containing water, but no binder, cover sands with moistures corresponding as nearly as may be to those in the comparison columns.

strength, and it is almost a general practice to add cereal type binders in order to "increase the green strength" of such mixtures. It is certainly true that cores can be made commercially from multiple bonded sands of this character than cannot be made commercially from the simple oil bonded sands.

[15] See footnote 9.

But if a given sand be tempered with say 8 per cent moisture only, with 8 per cent moisture and varying quantities of oil, and with 8 per cent moisture and varying quantities of cereal type binders, or with oil and cereal type binders, the simple water bonded sand invariably develops greatest green strength. This appears to be true at whatever moisture content the comparison is made, and it is equally true for green strength as measured in tension, in compression, or in cross bending (A. F. A. cohesiveness test method). Sufficient data to cover this point are given in Table 14. Additional data for some 10 different clean, clay free sands, with some 40 different binders, are available and the data given in Table 14 are thoroughly typical.

Green strength determinations are of little practical use in estimating the comparative values of binders. In the writer's opinion, green strength, as determined by any of the accepted methods, is due mainly to surface tension; most of the available binders reduce the surface tension of water and thus tend to reduce the green strength of sand mixtures containing them. On the other hand, the addition of most of these binders of the cereal type enormously increases the viscosity of water. The simple water bonded core mixture is "short;" it breaks sharply and tears readily; and the torn or broken core is difficult to repair; the same is true of core mixtures containing merely oils and water. Core mixtures containing cereal type binders, especially those of the glutinous or gelatinous types as distinct from the dextrin type, lead to cores which deform very appreciably without definite rupture. The deformed core can quite readily be repaired. The present paper is not concerned with other than oil binders except thus incidentally.

Conclusions

In a paper of this nature, the conclusions should no doubt follow naturally, and should be supported by the testimony adduced in the text. Some conclusions which are reasonably consistent with the above definition are included in the various piecemeal sections, and there is no need to repeat them. An acceptable general conclusion will become possible only when the piecemeal conclusions

can be correlated in such manner that each may be given its correct weight; it is hoped that this paper will encourage bringing to light enough added evidence from the work of others to make some such general conclusion possible.

Buckle implies that it is as important to report what man thinks as it is to report what Nature does, perhaps a rather egotistical implication. In this sense, however, the writer suggests the following general conclusions, subject to correction after review of further evidence:

Oils, as binders, possess three peculiarly excellent merits.

1. Relatively little oil is capable of strongly bonding a considerable quantity of clean sand.
2. The strength of oil bonded cores is but slightly affected by moisture.
3. The oil bond is so readily broken down by heat that the cores offer but little resistance to the shrinkage of hot castings and but slight resistance in cleaning out.

These merits are peculiar only in that they are found in combination in oil binders. In respect to strengths developable in dry cores, the cereal type binders, the glutrin-goulac type binders, and a host of less commonly used binders are almost as effective, pound for pound, as the oils; they are, in fact more effective than the oils for sands that contain appreciable quantities of clay. Pitch binders are not as effective, by any means, as the oils on a pound for pound basis.

The pitches are affected by moisture even less than are the oils, but in this respect the oils and pitches are almost alone; the strength of cores bonded with cereal type binders, with glutrin-goulac binders, etc., practically vanishes when the cores are kept for any length of time in closed green sand molds. On the other hand, the strength of cores, bonded with cereal type binders, etc., is but very slightly affected by long storage in an average foundry atmosphere with its 40 to 50 per cent relative humidity.

The cereal type binders are broken down by heat quite as readily, but not much more readily than oil bonds; they offer as

little resistance as the oils to the shrinkage of hot castings and as easy cleaning room problems. The pitches are not as readily broken down, nor as completely broken down by heat; they do offer an appreciable resistance to the shrinkage of hot castings, and they do at times offer serious cleaning room problems.

To offset the merits of the oils as binders, there are a number of marked disadvantages which seem to be peculiar to oils:

1. Clean sands, mixed with simple oils and water, are very weak in respect to the green strength recognized by the core maker as distinguished from the green strength measured in the laboratory.

2. Simple oil sand cores do not skin harden in any practicable time on air drying, as, for instance, when cores are stored on racks preliminary to charging them into the baking ovens. Such cores remain weak and fragile and the loss of unbaked cores is sometimes serious.

3. Simple oil bonded cores require careful attention in baking in order that they shall develop reasonably near maximum strength for a given oil cost. Improperly baked oils are often obscured by the behavior of auxiliary binders.

4. In respect to cost for equivalent strength, the oils are twice to four times as expensive as the cereal type binders, the glutrin-goulac binders, etc., and they are at even greater disadvantage as compared with the pitches.

Oils materially cheaper than pure linseed oil, on the basis of cost for equivalent strength, are not in sight so far as the writer's limited vision extends. The basis, viz., cost for equivalent strength, should be emphasized; cheap oils, on the gallon basis, will always be available.

The cereal type binders, particularly those of a glutinous or gelatinous nature, the gums, such as arabic and tragacanth, add materially to the green strength of sands so far as the core maker is concerned; he loses less cores in the making when he adds such binders. This increase in strength is not characteristic of binders of the glutrin-goulac type, nor of the dextrins, sugars, and the like, nor is it characteristic of the pitches.

The cereal type binders, the gums, the glutrin-goulac type, the

dextrins, sugars, etc., all yield cores which form strong surface skins on relatively short exposure to air drying at room temperature. Such cores acquire strength while standing on the racks, and the loss of green cores is diminished. This is not true for the pitches.

All of these binders, except the pitches, are comparable in binding value with the oils on a pound for pound basis so far as the strength of dry cores is concerned. On this pound for pound basis, the pitches are far less effective than the oils but the disadvantage is altogether the other way on a cost basis.

All of these binders, except the pitches, develop maximum strength in cores on mere drying at any temperature short of that at which the binders are destroyed.[16] The pitches develop maximum strength when merely heated to some 350-400 degrees Fahr.; keeping pitched bonded cores for long periods at the baking temperature serves little purpose nor does it bring about any deterioration of core strength.

The only objection to the use of the cereal type binders, glutrin-goulac, the gums, dextrins, sugars, is their reaction to moisture. They should be acceptable binders for cores which are set in dry sand molds, or for cores set in green sand molds when the latter are immediately poured. The addition of oils in such cases appears to serve little useful purpose.

Cores made solely with binders which are strongly affected by moisture cannot be used safely in green sand molds which are closed some hours before pouring off. The core strength almost vanishes, and the cores sag, or drop. The writer doubts that the moisture absorbed by such cores contributes to any important extent to "blown" castings, although he has frequently heard foundry comment to the contrary. But the strength required in cores to resist rough handling in the core room, in storage, and in the foundry is very much greater than is the strength required to resist stresses imposed upon the cores once they are set in the

[16] This statement should be qualified. Ordinary starch is an important component in many of the cereal type binders. Such starch requires gelatinization before it will develop core strength. Water is essential to the process, and the actual gelatinization commonly occurs within the core during the baking process, a temperature above 180 degrees Fahr. being an essential. An air dried starch core will be soft as to surface both as air dried and when baked. The same is not true of the so called "gelated starches" of which there are trade-named examples on the market.

closed mold. It seems to be excellent economy, therefore, to provide insurance against loss due to rough handling by adding the cheaper binders, and to insure against sagging of the moistened cores by adding oils, or pitches.

Very large cores often require high green strength sands, and clay is the only practicable material available to give this required strength. Such cores are frequently exposed for weeks to contact with moist sands and they must retain strength under these circumstances. The cost of sufficient oil to cover the dry strength requirements is prohibitive, and the baking of the oils in, say, dry sand pit molds is virtually impossible. The pitches are practically alone in their ability to cover this important foundry field.

Discussion

H. W. Dietert: You stated here that your bond was affected slightly by moisture. It seemed to me the moisture in core mixtures is a very vital point and some may misinterpret this statement. We have begun to feel that moisture in cores is about as important as in molding sand. And I would like to hear from some others as to whether their results check with Mr. Hansen's.

C. A. Hansen: We molded all of our core test mixtures rather wet, just as our regular core makers use rather wet mixtures in making production cores. So far as simple oil bonded core sands are concerned, moisture content is not of direct primary importance. The strength of the core made from a given mixture varies with the density of the core; the density may be varied by varying the ramming or by varying the moisture content. With a given ramming, the density will increase with the moisture content up to the point where the mixture becomes reasonably wet; further moisture additions have very little effect upon the density or strength.

I want to emphasize the point that the tests of oil bonded cores, as reported in my paper, refer to mixtures containing no auxiliary binders. Many of these commonly used auxiliary binders, particularly the cereal binders, behave peculiarly in respect to moisture.

There are some papers awaiting presentation which deal specifically with cereal binders so that I may be anticipating matters by bringing cereal binders into discussion at this point, but I want to say a little about them.

Some twenty years ago the only cereal binders that materially concerned the foundry were wheat and rye flours. These flours are composed essentially of starch cells cemented together by a glutinous protein

matter. This glutinous matter is responsible for the "doughy" or plastic nature of these flours when they are moistened, and it is also responsible for that "doughy" or plastic condition we find in moistened sand and flour mixtures. The glutinous matter is water soluble to a very large extent and it is an effective binding agent in the dried core. The strength of flour bonded cores, air dried at room temperature, is roughly proportional to the water soluble material in the flour used; the starch content does not contribute appreciably to the strength of the room temperature dried core. When the starch in wheat, rye, rice, sago, corn, potato, or other farinaceous products, or the starch separated from any of these products, is suspended in water and slowly heated, nothing in particular happens to the starch until the temperature reaches some 80 to 95 degrees Centigrade. Above this temperature range the starch changes in a very remarkable fashion; it becomes gelatinous—starch pudding. The gelatinous starch is a most effective binder; the ungelatinized starch is merely an inert filler.

If a freshly molded starch core is air dried at room temperature it will collapse as though made from merely sharp sand; it will behave similarly if baked at any temperature below the 80 to 95 degrees Centigrade necessary to gelatinize the starch; it will be a very strong core if baked at temperatures above 80 to 95 degrees Centigrade provided moisture is present when the gelatinizing temperature is reached and provided the starch can be kept sufficiently moist for the time necessary to gelatinize it. The starch present in the flours behaves in this same manner; it may become the best of binders under proper conditions, or it may remain merely inert filler. Generally, however, the surface of the core dries out too much before the gelatinizing temperature is reached; the surface strength of flour bonded cores is due mainly to water soluble glutinous material in the flour, and if the core is air dried before baking all of the strength attained may be due to the glutinous material.

During the World War wheat and rye flours were denied to foundries, and we turned to the most generally available substitute, corn flour. Corn flour has relatively little of the glutinous material present in wheat and rye flours; the housewife could not make good dough with corn flour, and the foundryman could not make "doughy" core sand mixtures with it. Probably the real reason why corn flours did not give satisfactory service in the foundry was that it was improperly handled; the cores were soft as to surface for reasons that can easily be inferred from the behavior of starch.

But starch, in flours or separated from them, can be converted more or less completely into water soluble dextrin by dry heat, and the conversion can be accelerated by adding small amounts of acid, nitric acid for example. The dextrin is not glutinous, and partial dextrinization of

corn flour will not make for "doughy" core mixtures, but the dextrin will concentrate on the surface of a core during the drying process, and the dextrin is a very effective binder however it be dried. The partially dextrinized corn flours yielded cores, and they were more nearly fool proof than the unprocessed corn flours or, for that matter, they are more nearly fool proof than wheat or rye flours.

We now have several binders of this type. They contain some 6 to 8 per cent protein matter, from 10 to 25 per cent dextrin, some 4 to 8 per cent moisture, and the balance mainly starch. These binders are fool proof in the sense that the dextrin content insures some sort of a usable core even though the binder is very improperly used. They are by no means fool proof in the sense that any fool can use them to full advantage.

Corn is our cheapest source of starch; corn contains other valuable ingredients which are commercially recoverable, principally corn oil and corn proteins, and corn starch may in a sense be considered a by-product. One of the largely used core binders is, I believe, a partially dextrinized corn starch, practically free of protein matter and containing approximately 50 per cent dextrin. Another binder, made by the same company, is a more or less completely dextrinized corn starch, containing practically no protein and upwards of 90 per cent water soluble dextrin. These binders are not glutinous in the sense that wheat flour, rye flour, or gelatinized starch is glutinous; they do not lead to "doughy" core mixtures. Corn starch is very much more finely divided than corn flour, and corn starch gelatinizes much more rapidly and much more completely than corn flour, so, in a sense, the dextrinized starches should be more nearly fool proof than the dextrinized corn flours.

We have still another type of core binder, a comparatively recent addition to the group. Both corn flour and corn starch may be gelatinized by heating them with water; the starch jelly may be dried and ground to a powder which will readily jelly again when moistened with cold water. The gelatinization of the starch is certainly not complete in these binders but they are, on the whole, reasonably fool proof.

It is not my intention to catalog binders for advertising purposes. All of the true cereal binders are good when correctly used; some are more nearly fool proof than others and generally speaking, the insurance against the fool is rather expensive; the insurance premium will usually be included in the price of the binder. On the other hand, I have found several so-called cereal binders that were viciously adulterated, one of them with upwards of 40 per cent fine sand, and several that were merely disguised. I think it is a fair assumption that the hocus-pocus twaddle that we have all heard in the foundry about core binders ought to be done away with, and I am fairly certain that when we have done away with it, we shall also have seen the last of adulterated and disguised core binders.

A MEMBER: I have been running a few tests recently with dry binders, and I find that the strength of our core drops right off with the core that hasn't any of the dry binder in it. It loses its strength with the absorption of moisture. Or at least that has been our experience.

C. A. HANSEN: So far as I know, the only commercially used core binders that are truly water proof are the pitches. The oils are reasonably water proof but less so than the pitches. The cereal binders, all of them, the glutrin-goulac type of binder, the sugar, molasses type, are excellent binders in dry cores, and the strength of the core practically vanishes if the cores are permitted to absorb moisture. The addition of pitches or oils to sands containing these other binders does not moisture proof the core in the true sense; the oil and pitch do not in the least interfere with the absorption of moisture by the other binders present.

Temperature Control in Aluminum Foundries

By Kirtland Marsh,* New Kensington, Pa.

There are undoubtedly innumerable aluminum castings made, over which no temperature control has been exercised other than that given by the unaided eye and judgment of the foundrymen, and a considerable proportion of them have probably been good castings at that. However, many foundries have learned from actual experience that close temperature control is not only highly desirable, but an absolute necessity for the most economical production of high quality castings.

Good temperature measuring equipment in the foundry provides close control over the melting operation and prevents the spoiling of many pounds of metal; it also insures that all molds are poured at the proper temperature and thereby eliminates one cause of many defective castings, namely, incorrect pouring temperatures. How often, when a lot of defective castings are produced in a foundry not equipped with suitable pyrometric equipment, are the defects indiscriminately blamed on too hot or too cold or burned metal, while the real cause, something quite different, is overlooked because no one can say the temperatures were correct and therefore not to blame?

For example, consider the case of a miss-run caused by a core shift. The miss-run may have every appearance of having been caused by too cold metal and in the absence of any actual knowledge concerning the metal temperature, the blame is so placed and the real cause is left unremedied with the result that additional miss-runs from the same cause are encountered. Of course, defects which are obviously due to other causes would not be blamed on metal temperatures, but the little defects which are just enough to cause rejection of the casting or render it of second quality are the ones that boost production costs and

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eat up the profits and are just the ones which the use of a good pyrometer will almost entirely eliminate.

Many foundries have found out for themselves that good pyrometers decrease production costs and improve quality, but for the benefit of those foundries not yet equipped with suitable pyrometers and those equipped with inadequate or improperly maintained instruments this paper has been prepared. It deals with the need of proper temperature control equipment and the reasons why it should be used in every aluminum foundry—the most suitable type of temperature measuring equipment for the purpose—and a description of equipment and control methods employed by some of the larger aluminum foundries.

This subject will be discussed under three general subdivisions as follows: temperature control of the melting and pouring operations, core baking, and heat treatment of castings made of certain aluminum alloys.

Melting Control

The melting operation requires close temperature control if the best results are to be obtained, because the time during which the metal is in a molten condition is a critical period; long soaking periods at high temperatures tend to increase the gas content, oxidation and iron absorption of the metal. Molten aluminum absorbs gases and the rate of absorption and the amount absorbed increases rapidly with the temperature.

The oxidation of the metal is slight in any case and iron absorption can be fairly well controlled, even in iron melting pots, by proper cleaning and coating of the pots. The principal ill effect, therefore, of overheating and long soaking periods even at moderately high temperature is the gassing of the metal. In order to melt the metal and bring it up to the proper temperature for pouring as quickly as possible, without overheating, reliable pyrometric equipment must be used. If the temperature of the molten metal is known at all times, gas absorption can be minimized and no metal need be sent to the molds too cold.

By making sure that the metal was not soaked too long at high temperatures or overheated, considerable improvement in

the quality of the castings would be assured and pyrometric equipment for that purpose alone would be well worth while.

Pouring Temperature Control

We have shown the benefits to be derived from the proper control of temperature during the melting operation, but accurate control of the pouring temperature is just as essential, and if such is not provided for, many defective castings will be produced which might otherwise have been avoided.

Whenever a new pattern is received by a foundry, it must, of course, be inspected to determine if it is properly constructed to meet the particular practices employed in that foundry. After this has been done and the best method of gating decided, size of flask, etc., determined, the best pouring temperature should be determined by an actual test in the following manner: Make up several molds and pour them with metal at different temperatures varying by 20 degrees Fahr., starting with metal which is known to be hot enough to pour the casting and ending when the first miss-run appears. Note the lowest temperature at which the mold can be poured without a miss-run and designate a temperature 20 to 40 degrees Fahr. higher as the best pouring temperature for production pouring of that particular mold. The addition of the 20 or the 40 degrees is a "factor of safety" to allow for variation in the molds, rate of pouring, etc. If a lower pouring temperature is used occasional miss-runs may be encountered and if higher pouring temperatures are used, not only must the metal be heated to a higher temperature in the melting pots or furnaces, which means greater absorption of gases, but the castings may show shrinks, draws and cracks.

The avoidance of overheating of the metal during the melting operation and pouring at the correct temperature will help to eliminate many operating difficulties and defective castings, but proper temperature control should by no means be considered as a cure-all. Even correct pouring temperatures cannot fully control shrinks, draws, metal cracks and to some extent gas holes, for these defects are principally controlled by proper gating, application of chills, the correct speed and steadiness of pouring,

slow feeding of risers, etc. For example, consider the gating of a mold. The gates and risers should be so arranged as to provide for progressive feeding of the mold, for that will eliminate the shrinks and draws caused by the shrinkage of the aluminum which occurs as it passes from the molten to the solid state. A given weight of aluminum in the solid or frozen condition occupies considerably less space than when molten. With progressive feeding, those portions of the mold which are filled first will be fed, as the metal in these portions solidifies, by subsequently poured metal which will still be molten. The molten metal should fill the gates and risers last in order that there will be molten metal available to feed those portions of the actual mold which were the last to be poured. Under such conditions there is always a supply of molten metal back of those portions which are freezing which will follow the shrinking metal and eliminate the formation of shrinks and draws. Even with proper gating to provide for progressive feeding, the occurrence of shrinks, draws and miss-runs is quite possible if the metal is not poured at the correct temperature. If the metal is poured too hot these defects are very liable to be encountered and also blow holes caused by gas from the mold and cores will be more frequent. On the other hand, if the metal is poured too cold, miss-runs will result.

The temperature to which the metal must be heated in the melting pots or furnaces will depend upon the drop in temperature between the furnace and the mold and the highest metal temperature required for any one mold. If several small furnaces or pots are used in the melting room, these may be operated at several different temperatures to accommodate the different molds being poured, but if the metal for all molds is melted in one furnace, it must be hot enough to accommodate the highest pouring temperature being used. In the latter case, it will be necessary to allow the metal for some molds to cool either naturally or assisted by the use of chill bars or the addition of cold metal, and if close temperature control is to be assured, pyrometric equipment must be provided for taking the temperature of the metal in the pouring ladles, as well as in the

melting furnaces. In a small foundry it would be possible to use one pyrometer for determining the temperature of the metal in the furnaces and also in the ladles, but it is generally better to have individual instruments for these two purposes.

Control of Core Oven Temperatures

Temperature control of the core ovens is also essential for the economic production of the best cores; the temperature at which they are baked and the rate at which they are brought up to that temperature has considerable effect on the quality of the cores. If cores are baked too hard, i. e., at too high a temperature, the casting is liable to crack as the metal freezes, because the strength of the core is greater than that of the hot metal. If under-baked, too much volatile matter is left in them which will volatilize when the hot metal strikes the core and the evolved gas will produce blow holes. Overbaking may also produce weak cores, because the binder is nearly all burned out, and such cores are liable to break in the mold and produce sand holes and inclusions.

Heat Treating of Castings

Some aluminum sand casting alloys show a considerable improvement in their physical properties when subjected to special heat treating processes. All heat treatment is done after the casting has been removed from the molds and very close temperature control is absolutely essential if the best results are to be obtained. Furnaces fully equipped with automatic temperature controllers and designed so as to give very uniform temperature distribution throughout the heating chamber are essential for these operations. The higher physical properties secured by heat treatment of castings poured from these alloys enables them to be used to great advantage where otherwise other materials would be required.

Having given at least some of the reasons why good temperature control equipment should be used in an aluminum foundry, we will now discuss the available pyrometric equipment and the methods of using it.

The Thermo-electric Pyrometer

A thermo-electric pyrometer is the only practical instrument for measuring the temperature of molten aluminum, and for the benefit of those who are not thoroughly familiar with this instrument a brief description will be given.

A thermo-electric pyrometer consists essentially of a thermo-couple, connecting leads and a voltage measuring instrument. The thermo-couple consists of two elements, of different chemical composition, in the form of two wires or one wire and a surrounding tubular element. Generally, the two elements are welded together at one end to form a good electrical and mechanically strong junction known as the hot-junction. The other end of these elements, whether they are actually joined together or not, forms the cold junction. If there is a difference in temperature between the hot and cold junctions a voltage or electro-motive force (e. m. f.) will be generated in the two elements, the value of which depends upon the temperature—e. m. f. characteristics of the two elements, the temperature of the hot junction and the difference in temperature between the hot and cold junctions. If the cold junction temperature is kept constant then the voltage generated by any given couple bears a fixed relation to the temperature of the hot junction and any instrument designed to measure the small voltage generated can be graduated to read the temperature of the hot junction directly.

It is seldom practical to connect the measuring instrument directly to the ends of the thermo-couple and leads are therefore used between the couple and the instrument. If copper leads are used, the cold junction of the couple is at the ends of the two thermoelements, but if the leads are of the same material as the thermo-couple or have the same thermo-electric characteristics as the couple, over the temperature range to which they will be subjected, then the cold junction will be at the ends of these leads. It is therefore common practice to use the latter type of leads between the couple and the instrument in order to remove the cold junction to a point of more constant temperature

than generally exists at the ends of the thermo-couple elements themselves.

The voltage measuring instrument may be a deflection instrument of the galvanometer type, like the common direct current voltmeter, a potentiometer or an instrument embodying the principles of both of these. No description of the construction of these several types of instruments or the principles upon which they operate will be given in this paper. For information on this phase of the subject, the reader is referred to Technologic Paper No. 170 of the Bureau of Standards entitled "Pyrometric Practice" by Foote, Fairchild and Harrison.

When the voltage measuring instrument is of the galvanometer type, the accuracy of the instrument depends upon the constancy of the external resistance, i. e., the resistance of the couple, load and connections. If the value of the external resistance changes, due to loose connections or any appreciable change in the length of the leads, then the reading of the instrument will be in error by an amount which is a function of the correct value of external and internal resistance and the change in external resistance. Therefore, all connections should be kept tight and the resistance of the leads should not be appreciably changed by lengthening or shortening them.

The Cold Junction

In any pyrometer installation due attention must be given to the cold-junction of the thermo-couples, for the accuracy of the installation depends upon a constant cold junction temperature being maintained or a varying cold junction temperature being compensated for. By the use of special lead wires having the same thermo-electric characteristics as the thermo-couple the cold junction may be moved from the end of the couple itself to a point of constant temperature or to the measuring instrument where some special device compensates for changes in the temperature of the actual cold junction.

At the bottom of a pipe driven from ten to fifteen feet under ground the temperature is practically constant from day to day providing it is not too near any under ground furnace flues,

steam pipes, etc. The temperature at the bottom of such a cold junction well may vary with the season of the year, but such changes will be gradual and a check every month or two should be sufficient to detect any serious change in cold junction temperature. By extending the special lead wires—often referred to as auxiliary lead wire, thermo-couple extension and sometimes, erroneously, compensating leads (the leads themselves being unable to compensate for fluctuating cold junction temperatures)—to the bottom of such a well, the cold junction temperature can be maintained constant. This method is commonly used and is very satisfactory.

To properly adjust the instrument the actual cold junction temperature must be known, for in the case of the galvanometer type instrument without any automatic cold junction compensator or with a mechanical type of compensator, the zero position of the pointer, i. e., the position of the pointer with no e. m. f. impressed on the terminals of the instrument, as is the case when the instrument is on open circuit or not connected to any couple,—must agree with the cold junction temperature or, in other words, with the instrument disconnected the pointer should read the temperature of the cold junction. If it does not, then it must be made to do so by means of the zero adjuster on the instrument. In the case of a potentiometer equipped with a manually operated cold junction compensator the actual cold junction temperature must be known before this compensator can be properly set. As commonly arranged, i. e., with the cold junction at the bottom of a well, it is necessary to determine the temperature of the cold junction at the bottom of the well and this may be done by means of a mercury filled thermometer lowered down the well. Such a procedure, however, is not extremely accurate because the thermometer reading may vary as the thermometer is withdrawn from the well—particularly if water has condensed in the well, and wet the thermometer bulb. It is otherwise not entirely satisfactory, since the thermometer is very liable to be broken and because at least five minutes should be allowed for the thermometer to reach equilibrium.

By a very simple arrangement of the switch and leads the necessity of taking the temperature at the bottom of the cold

junction well may be eliminated. Such an arrangement is shown in Fig. 1.

In this diagram, two couples are shown connected to one indicator. From the ends of the thermo-couples auxiliary leads of the same material or having the same thermo-electric characteristics as the thermo-couples, extend to a common zone box where they are soldered to copper leads extending to the selector switch. A common cold junction couple made up of auxiliary lead wire is used and in order that it may serve either couple it is connected in between the switch and the indicator by means of copper leads, with the soldered connections between the actual cold junction couple and the copper leads in the common zone box. As long as all connections between the auxiliary lead wire

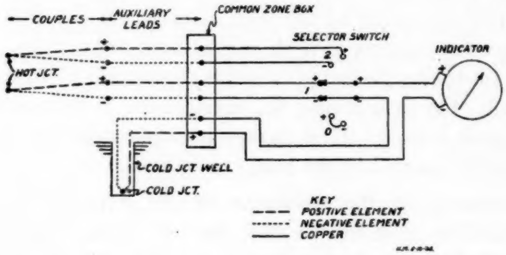

FIG. 1—WIRING DIAGRAM FOR INDICATING PYROMETER INSTALLATION

and the copper leads are kept at the same temperature the length of copper leads does not affect the e. m. f. generated. It is not necessary that these connections be kept at a constant temperature as long as the temperature of all of them is the same and the common zone box, the purpose of which is only to keep all these connections at the same temperature, may be subjected to daily temperature fluctuations without affecting the accuracy of the installation.

The switch is shown set on position 1 and the indicator would show the temperature at the hot junction of the couple connected to that switch position. As many couples can be connected

to the switch as there are positions or points on the switch. On the zero position it will be noted that the positive and negative poles or contacts are short circuited with a short length of copper wire and that is where this arrangement differs from the usual arrangement using a common cold junction couple. With the switch on any position but 0 the common cold junction couple is connected in series with a thermo-couple and the indicator, but with the switch on the zero position, the common cold junction couple is connected directly to the indicator and with reversed polarity. So connected, the indicator will show the temperature in the common zone box providing the zero setting of the indicator agrees with the temperature of the cold junction at the bottom of the well. If the indicator does not read the common zone box temperature, the zero setting does not agree with the cold junction temperature, but it can be made to do so by adjusting the pointer by means of the zero adjuster until it does read the zone box temperature. With this arrangement, there is no necessity for taking the temperature at the bottom of the cold junction well. For determining the temperature in the common zone box a small mercury filled thermometer permanently installed or temporarily inserted in the box, can be used.

Theoretically, the resistance of the external circuit with the switch on 0 should be that for which the instrument was calibrated, but actually this is not essential if the instrument has an internal resistance of 200 ohms or over. For example, if the resistance of this circuit was 5 ohms less than the external resistance for which the instrument was calibrated the error in the reading of the instrument would be practically 5/200 or 2.5 per cent, but as the temperature at the bottom of the well is generally about 70 degrees Fahr. and the common zone box should not be located where the temperature will be much above 120 degrees Fahr., the difference in temperature is only 50 degrees Fahr. and 2.5 per cent of this is only 1.25 degrees Fahr., which would be the error introduced in the cold junction setting by the 5 ohms lacking in the external resistance of this circuit. This is generally as close as the zero setting can usually be made anyway and is, therefore, generally satisfactory.

Automatic Cold Junction Compensators

Several manufacturers of pyrometers do, or will if desired, equip their instruments with automatic cold junction compensators. Some of these compensators are of a mechanical and some of an electrical type. When automatic cold junction compensators are used the cold junction must be extended all the way to the temperature sensitive element of the compensator so that any change in cold junction temperature is accompanied by a like change in the temperature of the temperature sensitive element of the compensator.

One mechanical compensator consists of a bi-metallic spiral interposed between the hand operated zero adjuster and the control spring on the moving coil and so designed that after the zero position of the pointer has once been set to agree with the cold junction temperature the bi-metallic spiral changes the zero position of the pointer in accordance with any changes in the cold junction temperature. With such a device, the auxiliary leads should extend inside the instrument case where the bi-metallic spiral is located, for it is quite possible, when the instrument is located so that cold drafts or radiation from an open furnace can strike it intermittently, for the temperature inside the instrument to differ considerably from the temperature just outside of the case. This does not mean that the binding posts must be inside the instrument case, but that auxiliary lead wire should be used from the inside ends of the binding posts and that these posts should be of heavy enough cross section to eliminate any possibility of appreciable differences in temperature existing between the outside and inside ends of the posts. With such an arrangement, the true cold junction will be inside the instrument and it will always be at the same temperature as the temperature sensitive element of the compensator. One manufacturer even goes so far as to make these binding posts, on instruments in which the temperature sensitive element of the compensator is located inside the instrument, of the same material as the thermo-couple leads and then to use leads of the same material from the inside ends of these binding posts.

One electrical type of compensator is constructed on the

Wheatstone bridge principle. The temperature sensitive element is in one arm of the bridge and when the cold junction temperature varies from that for which the instrument was calibrated, an e. m. f. is added or opposed to that generated by the couple to compensate for the e. m. f. lost or gained by the decrease or increase in temperature difference between the hot and cold junctions caused by changes in the cold junction temperature. With this type of compensator the zero position of the galvanometer must always be maintained at a specified position on the scale, generally 75 degrees Fahr. or 25 degrees Cent. Furthermore, the current through the bridge must be kept constant and this is accomplished by turning the selector switch to the check position occasionally and turning the rheostat handle until the pointer of the instrument is at the check position marked on the scale of the instrument. This adjustment is very simple and does not have to be made very frequently. One ordinary No. 6 dry cell operates the compensator and will last for months.

Both of the above types of compensators can be made to function satisfactorily, although in quantity production it is probably easier to reproduce identical units of the electrical type than of the mechanical type, which is one reason to believe that units of the electrical type may be more consistently good than those of the mechanical type.

Thermo-Elements

There are three different thermo-elements in common commercial use; platinum vs. platinum-rhodium, chromel vs. alumel and iron vs. constantan. The platinum vs. platinum-rhodium can be used up to 3000 degrees Fahr. or higher, the chromel-alumel up to 2500 degrees Fahr. and the iron-constantan up to 1800 degrees Fahr. Although each of the above can be used at somewhat higher temperatures than those mentioned they are not commercially practical above those temperatures. The platinum vs. platinum-rhodium couples require quartz or ceramic protection tubes, are costly and since other couples are more satisfactory, are not commercially used for measuring the temperature

of molten aluminum. The chromel-alumel and the iron-constantan couples are both satisfactory for measuring the temperature of molten aluminum and although chromel-alumel is probably more generally used, the type of iron-constantan couple consisting of a constantan wire element inside a tubular iron element has certain advantages for some applications.

Since molten aluminum will gradually alloy with both the chromel-alumel and iron-constantan couples, it is essential for economical reasons that, when used continuously in molten aluminum, protection tubes should be used over the couples or that other means be employed to keep the molten aluminum out of contact with the thermo-couple. However, even as the molten aluminum attacks the thermo-couples so will it attack the protection tubes and as yet no metallic tubes have been found which will satisfactorily resist this attack. Ordinary cast iron seems to offer as much resistance to molten aluminum as any metal, even including the heat resisting alloys, particularly if covered with an oxide skin (rust or scale). Ceramic tubes are not satisfactory for this purpose, since they are easily broken by mechanical shock and cannot be plunged directly into molten metal while cold.

An Effective Coating for Tubes

A very effective method of protecting thermo-couple protection tubes against attack by the molten aluminum consists in applying a protective coating to the tube. Whitewash made up of hydrated lime mixed with water in the proportion of one part of lime to one part by volume of water makes a wash that can easily be applied with a brush and produces a continuous and effective coating. If the tube is heated before the wash is applied, a better coating is obtained, but the tube should not be much above 180 degrees Fahr. when the wash is applied. Instead of applying this wash with a brush, the wash may be kept in a container about 6 inches in diameter and of the proper depth and the heated tube plunged into the wash once and quickly withdrawn. Another effective coating can be made by applying a wash consisting of one part of graphite—the ordinary plumbago such as is used in

foundries is very satisfactory—to two parts by volume of water. This wash may be applied with a brush or by the dipping method.

When the thermo-couple protection tube is suspended over an open pot and lowered into place for use, the above coatings are very satisfactory, but when the tube must be inserted through a hole in the wall of an open hearth furnace the coating is very apt to be scraped off in places, leaving the tube exposed to attack and after the molten aluminum has once started to alloy with the tube subsequent coatings will not stop it, for the affected spot cannot be entirely freed from aluminum. A coating much more resistant to abrasion can be secured, if, instead of plain water the lime or graphite be mixed with a solution of 25 per cent by volume of commercial sodium silicate solution and 75 per cent water. The sodium silicate acts as a binder and produces a coating which will not be easily abraded in handling.

The protection tubes should be recoated once a day and before a fresh coating is applied all aluminum should be removed and any loose lime or graphite scraped off. When used in an open hearth furnace where the tube is subjected to more abrasion it may be found advantageous to recoat more frequently.

It might be mentioned at this time that the same lime wash (lime and water) is equally effective when used on the inside of cast iron melting pots, ladles, skimmers, etc., not only to protect the iron from attack, but also to prevent contamination of the aluminum.

Quick Reading Apparatus

For continuous use in melting pots or furnaces a thermo-couple protected by an outer tube is very satisfactory, for although considerable time is required for the protection tube and the thermo-couple to reach temperature equilibrium and correctly indicate the temperature of the molten metal, once heated up, the couple follows the temperature of the molten metal with very little lag and the outer protection tube reduces the frequency of thermo-couple replacements. Such an arrangement would not be satisfactory for intermittent use in pots or furnaces or for measuring the temperature of the metal in pouring ladles because of the long time required for the couple to attain the temperature

of the molten metal. A very much quicker reading couple is required for this purpose, in fact, a couple used for taking the temperature of the metal in a pouring ladle should be capable of indicating the true temperature in a fractional part of a minute, say 10 or 15 seconds.

Fortunately, thermo-couples can be made up or purchased which are capable of accurately measuring the temperature of molten aluminum very quickly. One manufacturer of pyrometers furnishes a couple made up of relatively fine wire in a holder consisting of a metal tube with a magazine handle. A considerable length of each element of the couple is wound on spools in the magazine and extends through and beyond the tube a few inches; these wires are twisted together at the ends and when used the twisted ends are inserted in the molten aluminum to a depth of a few inches. Beyond the end of the tube these wires are not insulated and it is therefore a simple matter to cut off the ends whenever necessary, draw out a few more inches, twist the ends together and be ready for another measurement. Theoretically, there are several disadvantages to this type of construction: First the wires being uninsulated beyond the end of the tube are subject to attack for the full depth to which they are immersed in the molten aluminum and unless the wires are sufficiently oxidized to be completely covered with an insulating layer of oxide or scale the real hot junction will be at the surface of the aluminum and not at the twisted ends. This means that the surface temperature is being measured. When the couple is withdrawn, more or less metal will cling to the two wire elements of the couple and the next time the couple is used it should be immersed to at least the same depth or the aluminum adhering to the wires may cause a short circuit above the surface of the metal and cause a low reading of the instrument. However, this couple, if properly used, should prove quite satisfactory, for even if it does measure the temperature of the surface of the metal there should be very little difference between the temperature at the surface and at a point below the surface in a recently filled ladle. The couple, being made of fine wire, has little heat capacity and should, therefore, give a very quick reading.

Another quick reading couple used very extensively by one

company operating several foundries consists of a chromel-alumel couple insulated with asbestos to within about ½ inch of the ends of the wires, which are not even twisted together.

No. 8 B. & S. Ga. chromel-alumel wire is used and the insulation is that type of peculiar asbestos insulation frequently used on auxiliary lead wire. As far as is known, no pyrometer manufacturer carries chromel-alumel wire in this size and with this type of insulation in stock, so it has always been necessary to purchase the wire and have it specially insulated. We believe that the peculiar character of this insulation is in a large part responsible for the satisfactory service which these couples have given. When heated, the wax on the asbestos burns off, but the remaining asbestos is tough and seems to stand up better than asbestos cord wrapped or woven around the elements. The junction between the two elements of the couple is formed by the molten aluminum and a steady reading is obtained a very few seconds after the couple has been immersed in the molten metal. The asbestos insulation eliminates any possibility of short circuits at the surface of the metal so that the temperature is measured as far below the surface as the couple is immersed. To hold the two elements together short lengths, about ⅛ inch, are cut from a piece of seamless steel tubing, flattened slightly, slipped over the two wires and then formed like a figure 8 around the two wires. These rings are spaced 8 or 10 inches apart and hold the two wires together very satisfactorily. The leads may be soldered directly to the couple or a thermo-couple connector manufactured for that purpose may be used.

In use, the chromel-alumel elements are gradually dissolved away and the asbestos insulation gradually breaks away, but the elements and the insulation wear at about the same rate and it has been found that couples used to take readings every five or six minutes for nine hours a day require to be cut back an inch or two only once every three days. This open junction type of couple, although quite contrary to the ordinary conception of a thermo-couple, is quite as accurate when used in molten aluminum as one with a welded hot junction. It is not necessary to remove any aluminum clinging to the wires when they are withdrawn nor is it essential that they be immersed to the full length of the

adhering aluminum the next time they are used as long as the asbestos insulation extends two or three inches below the surface of the metal. These couples are generally made up about thirty-six inches long and can be used until they are not more than twelve inches long or less.

By means of either of the above quick reading couples, the temperature of each and every ladle of metal can be quickly and accurately determined and there should be no reason for any aluminum casting being poured at other than the best pouring temperature.

Calibration of Couples

It is an extremely simple matter to check or calibrate either the above quick reading couples or a couple protected with an outer sheath by leaving the couple in the metal while it cools down to the freezing point, readings being taken every half minute or minute. In such a procedure the readings gradually decrease as the temperature of the metal drops until the freezing point is reached and then the temperature remains practically constant until all of the metal, or at least that in the immediate vicinity of the couple, is frozen. The time temperature curve for a quick reading couple in molten aluminum will show a sharp change in direction when the freezing point is reached, but the same curve for a couple in a protection tube may show a less abrupt change in direction due to the lag in temperature change introduced by the heavy walled protection tube.

Given the temperature at which the metal freezes and the reading of the pyrometer when freezing is taking place, as shown by the reading of the pyrometer remaining constant or practically so over an appreciable length of time, the correction to the pyrometer is the difference between the two. For example, if the freezing temperature of the metal was 1160 degrees Fahr. and the pyrometer read 1155 degrees Fahr., then the correction to the pyrometer reading would be + 5 degrees Fahr. If the couple is not left in the metal until it has frozen solid it can be easily withdrawn and the mushy metal in the crucible or ladle dumped out before it has set. The metal on the thermo-couple can be melted off in a ladle of hot metal.

Most alloys of aluminum cannot be satisfactorily employed for the calibration of pyrometers by the freezing point method because the thermal arrests are not large enough or sharply enough defined to clearly register on the usual shop pyrometer. However, there are some alloys which experience has shown to be suitable for calibration of plant pyrometers by the freezing point method and two of these are given in Table 1.

Table 1

ALUMINUM CASTING ALLOYS SUITABLE FOR CALIBRATION OF PLANT PYROMETERS

Composition by Per Cent						Total	Alloy	Approximate Freezing
Cu	Si	Zn	Fe	Mg	Mn	Impurities	No.	Point
7.0–8.5	....	0.2m	....	..	....	1.7	12	1,160° F.
0.15m	12.0–13.0	0.2m	0.8m	T	0.7m	...	47	1,071° F.

m=maximum.

A ladle of miscellaneous scrap or secondary metal should not be used for this purpose unless its freezing characteristics have been carefully determined by previous tests with standard pyrometric equipment of known accuracy.

Frequent Calibration Essential

Every pyrometer installation should be checked and calibrated periodically to make sure that it is reading correctly, for there is not a pyrometer on the market nor can one be made that is absolutely infallible. The temperature E. M. F. characteristics of the thermo-couples may change after being in use, loose connections not visible to a casual observation or even inspection may develop, the zero setting of the galvanometer may shift or be changed either accidentally or maliciously—in fact, there are many things which may occur to cause a pyrometer to read incorrectly.

In an aluminum foundry it is a very simple matter to calibrate a pyrometer by the freezing point method, and although the instrument will be used at a temperature 200 or 300 degrees Fahr. higher than the temperature at which it can be readily calibrated by the above method, it is fairly safe to assume that if it reads correctly at the freezing point of one of the aluminum

alloys it will also read correctly at a temperature 250 degrees Fahr. higher. However, if there is an appreciable error, say 10 to 20 degrees Fahr., at the freezing point of aluminum, the error at a temperature of 250 degrees higher may be greater or less, depending on the type of couple and the cause of the discrepancy.

Recording Pyrometers Valuable

For melting pots or furnaces an indicating pyrometer serves very well, but by adding a recording pyrometer, a reliable record of the exact operation of the furnaces can be obtained, which is, in some cases, very desirable.

For core ovens, either indicating or recording thermo-electric pyrometers or industrial thermometers, indicating or recording, may be used. In the case of core ovens where the rate of baking affects the quality of the cores there is more need of recording instruments than in the case of melting furnaces. A single record recording thermometer costs less than a single record thermo-electric pyrometer and properly installed should be just as satisfactory, but if several temperatures are to be recorded, a multiple record pyrometer may be cheaper, and therefore, the question of which type of instrument to use depends largely on the cost of the complete installation.

Automatic temperature controllers on core ovens should provide for the most uniform baking that can be obtained and should be well worth while in many instances.

Description of Equipment in Use in a Foundry

The following is a description of the pyrometric equipment for temperature control and the method of using it in one of the sand casting foundries of the company with which the writer is associated. It shows the extent to which this company believes temperature control must be carried for the proper operation of an aluminum sand casting foundry.

Melting Room

In the melting room at this foundry there are 24 tilting pot furnaces of 400 pounds capacity and 9 stationary furnaces of

300 or 400 pounds capacity used for melting aluminum for sand castings.

Each tilting furnace is equipped with one thermo-couple suspended by a counterweighted cable or chain; when not in actual use it hangs above the furnace. The couple consists of No. 8 B. & S. Ga. chromel-alumel elements, asbestos insulated, and is connected to an indicating pyrometer by means of auxiliary lead wire and selector switch. The couple is protected by a cast iron

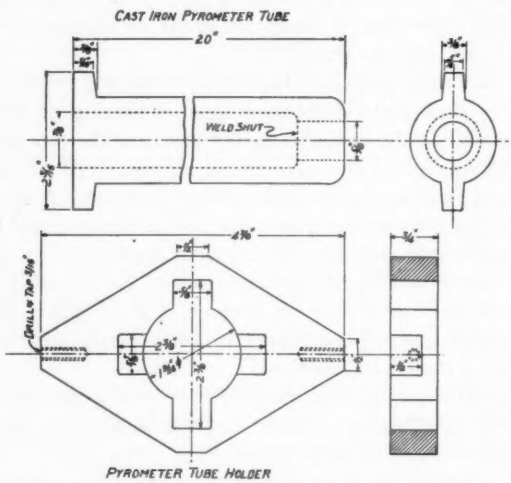

FIG. 2—CAST IRON PYROMETER TUBE AND HOLDER

sheath, supported by a holder attached to the cable. The couple simply rests in the sheath with the hot junction at the bottom.

The indicating pyrometer, selector switches and signal board switches are located inside a brick enclosure, while the signal boards are outside, above the pyrometer booth. The signal boards consist of a series of numbers on glass, corresponding to the furnace numbers, with lamps behind each number. On the signal switch board in the booth there is a switch for the lamp behind each number, by means of which the pyrometer man can illuminate each number as desired. There is also a whistle cord in the

pyrometer booth by means of which a whistle can be blown as an auxiliary signal.

Fig. 2 shows a dimensioned drawing of a cast iron pyrometer tube and the holder for the tube. The supporting cable or chain is attached to the holder by means of two machine screws

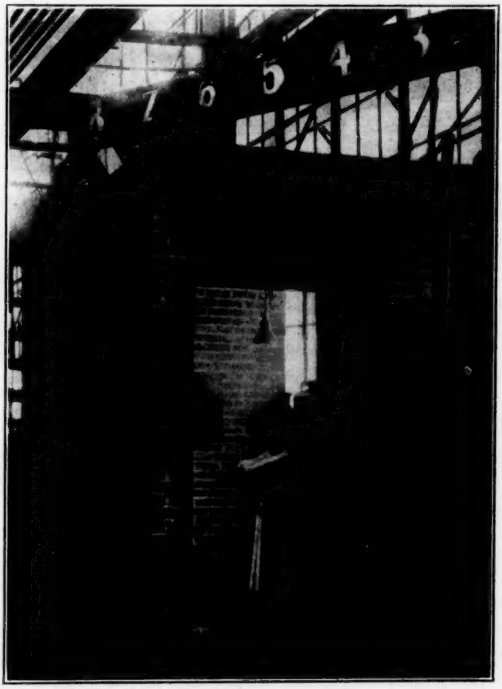

FIG. 3—CENTRAL PYROMETER STATION AND SIGNAL BOARDS

which are inserted in the drilled and tapped holes in the end of the holder. The tube is securely held but can be easily removed whenever necessary.

Fig. 3 shows the exterior of the station, a small portion of the interior and one of the signal boards. The numbers were all illuminated simply to make them visible in the photograph.

Fig. 4 shows the three selector switches mounted on the vertical panel at the back of the desk and the indicating pyrometer above. In this picture the glass dome which protects the instrument from dust and fumes was removed while the picture was being taken. To the left of the selector switches can be seen the signal board switches by means of which the numerals on the signal boards are illuminated.

As soon as the complete charge in the cast iron pot has been melted down, the thermo-couple and sheath are lowered into the

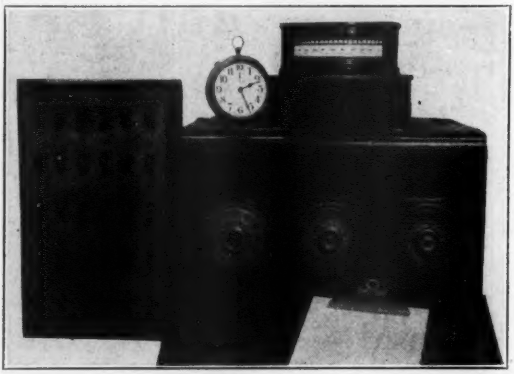

FIG. 4—MELTING FURNACE PYROMETER AND SIGNAL SWITCH BOARD

molten metal, by the furnace tender, to a depth of immersion of about 12 inches. The pyrometer man observes the temperature of the metal in each pot every few minutes and as each charge reaches the proper temperature, he illuminates the corresponding number for that furnace on the signal board. The furnace operator then adjusts the burner on that pot to hold the temperature constant, extinguishing the burner and relighting it later, if necessary, until the furnace is poured.

If, by any chance, the furnace operator fails to observe the signal or observing it, fails to act accordingly, the pyrometer man blows one blast on the whistle, which reminds him to observe the

signal lights for his bank of furnaces. Just before a furnace is poured, the time and the temperature of the metal are taken and recorded by the central station pyrometer man and the couple is then pulled up out of the way.

At the end of the day, the cast iron thermo-couple sheaths are carefully cleaned to remove any clinging aluminum or loose protective coating and then recoated. The suspension cable is long enough to enable the operator to lower the sheath to a position where it can be easily handled for cleaning and coating without actually removing it from the holder. The protective coating is put on with a whitewash brush while the sheath is still warm, but below the boiling point of water; it consists of whiting (French chalk or calcium carbonate) mixed with enough water to give a rather thick, although still quite fluid, wash. Whiting is used in making up the wash in place of the lime (calcium hydrate) previously mentioned, because it is believed there is a tendency for the whiting wash to adhere to the tube more satisfactorily. It might also be mentioned that each cast iron pot is scraped out and recoated with the same wash each day in practically the same manner as the sheaths.

Properly coated each day, these cast iron sheaths last from 6 to 8 months; the ultimate failure is usually caused by oxidation of the iron. The protective layer of whiting prevents the aluminum from coming in contact with the cast iron and therefore prevents any alloying or solvent action on the tube.

Tests made by the writer of many different heat-resisting alloys have failed to disclose a single one which would satisfactorily resist the alloying action of molten aluminum and since a cast iron tube coated with lime or whiting can be used each day for 6 or 8 months, they are more economical than an alloy tube, which would also have to be coated in the same manner if it were to last for a reasonable length of time.

The metal in the tilting pot furnaces is poured into 100 pound pouring crucibles which are then taken into the floor cast-

ing room on buggies. Before a crucible of metal can be taken to a mold it must be checked at the pouring station by an inspector. At each pouring station in the floor casting room there are two quick reading thermo-couples connected to an indicating pyrometer by means of auxiliary lead wires and a two point selector switch.

Fig. 5 shows the indicating pyrometer and selector switch mounted on the building column and the two quick reading ther-

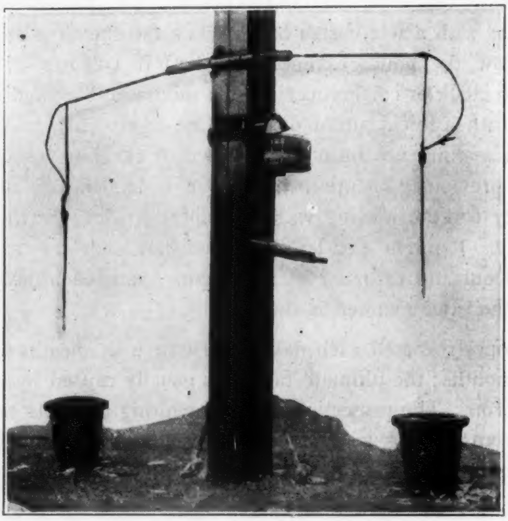

FIG. 5—POURING STATION IN FLOOR CASTING ROOM

mo-couples suspended from chains attached to a short length of ½ inch conduit anchored in a close-wound spiral steel spring. The spring provides flexibility and enables the operator to pull the couple down into the metal. While the temperatures are being taken, the crucible of metal stands on the pedestals beneath the couples. In order to show the essential features of this photograph, the background was blocked off.

Fig. 6 shows a new couple all ready to be connected to the lead wires. The steel bands, made of short length of seamless steel tubing, which hold the two elements of the couple together, can be distinguished in the picture.

If the inspector finds that the temperature of the metal is too high for the particular mold for which it is intended, it is allowed to cool naturally or by the addition of clean solid pieces of the same alloy. No light or dirty scrap is used for cooling a ladle of metal, because such material is a source of much trouble in causing the formation of inclusions and porosity in the castings.

For each ladle of metal passing through the pouring station, the inspector records the temperature of the metal as received from the furnace, the furnace number, the time it was received, the time and temperature at which it was sent to the mold, and the number of the job on which the metal is to be used.

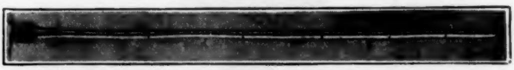

FIG. 6—QUICK READING THERMO-COUPLE AND CONNECTOR

From the pouring station and central pyrometer station records, the history of all the metal used for any job can be traced back from the mold to the composition sheet in the melting room, and it can be readily ascertained whether a defective casting was caused by improper temperature conditions.

As shown in Fig. 6, the pyrometer at the pouring station consists of an indicator connected to two quick reading couples of No. 8 B. & S. Ga. chromel-alumel wire, asbestos insulated and made up with an open hot junction as previously described. Every three days, the hot junction ends are cut back about 3 inches to keep the couple in good condition, for although the asbestos insulation wears off at about the same rate as the wires are consumed, it may become frayed further back and constitute a potential source of trouble.

There are three pouring stations serving a casting floor about 100 feet by 240 feet. The pyrometers at these stations are calibrated each morning by the freezing point method. Auxiliary cold junction couples buried to a depth of about 15 feet maintain a constant cold junction temperature.

Bench Molding Procedure

For the major portion of the bench work a slightly different procedure is followed. The pouring crew take the metal directly from the stationary furnaces with hand ladles in which it is carried to the pouring station in small buggies where the temperature of the metal is taken with a quick reading thermo-couple. If the metal is too hot, it is allowed to cool naturally or by the immersion of iron chills which are well limed.

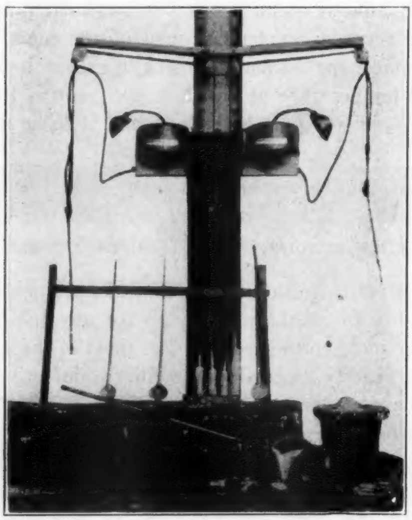

FIG. 7—BENCH POURING STATION

Fig. 7 shows two indicating pyrometers and the quick reading couples connected to them. The iron chills and skimming ladles can be seen below the indicators and in the foreground is one of the small buggies and a ladle of metal. At this station, the quick reading couples are suspended by counterweighted chains. The pouring ladles for the bench work are small and the heat losses between the pouring station and some parts of the

bench room are appreciable so that allowance is made for the drop in temperature between the pouring station and the bench.

Core Oven Procedure

The core ovens in this foundry are oil fired and each one is equipped with a thermo-couple connected to an indicating pyrometer by means of auxiliary lead wire and a selector switch. With the aid of this pyrometer the ovens can be operated according to any predetermined schedule and baking conditions can be duplicated from day to day.

Heat Treating Department

In the heat treating department there are four pit type and two car type electrically heated and four steam heated heat treating furnaces, all automatically controlled.

The electrically heated heat-treating furnaces, besides being equipped with automatic temperature controllers, are also equipped with absolutely independent recording pyrometers and temperature limit safety fuses. The advantage of the independent controlling and recording pyrometers is that in case anything goes wrong with the controller, the recorder shows just what treatment has been accorded to the load and the proper procedure can be determined at a glance. The temperature limit fuse is a safety device to cut off the power before the load is melted down and the furnace ruined in case the controller fails and the operator does not observe the condition in time to remedy it. The foreman of the heat treating department is required to observe the automatic control instruments and recording pyrometers every half hour and record the setting of the controllers and the temperature readings as shown by the recorders.

The steam heated furnaces are equipped with pressure regulators which maintain a uniform temperature in the chambers and in addition the temperature of the chambers are recorded on a recording pyrometer.

These heat treating furnaces handle castings ranging in size from pistons and bearing caps up to motor bus frames over 6

feet long and produce a uniform temperature throughout the load to within ± 10 degrees Fahr.

Summary

This paper has been prepared to show why close control of the melting and pouring temperature in an aluminum foundry is so essential and what results may be expected of good pyrometric equipment properly installed, maintained and used. The make of instrument to be used must be decided by the purchaser and there is a wide field from which to make a selection. The manufacturer will furnish the complete equipment and full instructions for the proper installation of the same. Detailed descriptions of a few special features such as the asbestos insulated quick reading couples, the special wiring diagram of an indicating pyrometer installation, pyrometer tube and holder, etc., have been included and if anyone desires to incorporate any of these features in an installation they are at liberty to do so, but will probably have to undertake this themselves because, in so far as we know, no manufacturer regularly furnishes them.

Discussion.

H. L. Parr: Do you find it necessary to check the pyrometer for accuracy as often in using it in aluminum as it would be necessary in high temperature such as brass?

K. Marsh: A pyrometer used for measuring the temperature of molten aluminum is not subjected to such severe conditions as one used in brass, and it is quite probable that it would not be found to be out of calibration as often as one used in brass. However, in any thermo-electric pyrometer, there are many possible causes for inaccuracy and trouble may develop at any time, and the only safe way is to be sure. The question of the necessary frequency of calibration is largely a matter of insurance. In the foundry described, it is a very simple matter to check the pyrometer by a freezing point determination, for there is always some alloy being melted which is suitable for calibration purposes, and it is, therefore, only necessary to bring in a ladle full and make the calibration. Thus, the cost of the daily calibration is very small and a few castings spoiled by incorrect metal temperatures would offset the cost of many calibrations. A daily calibration in this foundry is, therefore, cheap insurance and believed to be well worth while.

CHAIRMAN N. K. B. PATCH: Has your routine developed the fact that there is material trouble, or does the routine establish the fact that it is largely a matter of routine and doesn't need to be done any more so than it does in brass, or as much?

K. MARSH: I have no statistics here to show how frequently the daily calibration shows the pyrometer to be in error but believe that it is not oftener than an average of once a month and probably even less frequently, than that. Where calibration costs are considerably higher than in the case mentioned, a daily calibration might be a burden and a program of a daily inspection,—to determine if the instrument, leads and couple are in apparently good condition and the zero setting is in agreement with the actual cold junction temperature,—and a real calibration once a week or once or twice a month might be sufficient.

If pyrometers are to be of the greatest value, those who use them must have full confidence in them and a frequent calibration and O. K. ticket certainly breeds confidence.

Temperature Control in the Brass Foundry

By H. M. St. John,* Detroit, Mich.

In the foundry itself there has always been a certain prejudice against pyrometric control of metal temperatures. Until rather recently there have been good reasons for this prejudice. The best available equipment was delicate and not altogether reliable. It could not be put into the hands of a foundry worker with satisfactory results. From the foundry superintendent's point of view pyrometers were not practical. This condition has changed. In the present state of the art, foundry pyrometers, while far from perfect, are practical. The foundry superintendent, once he has become familiar with the use of pyrometers, favors them because they relieve him from much tiresome detail and reduce his scrap.

Whatever opinion one may hold regarding the accuracy of the human eye in judging metal temperatures, it must at least be admitted that the expert eye is the result of long experience and constant practice. No foundry has more than one or two experts whose judgment of temperature is really good and if, for any reason, these men are absent or off color, the castings suffer.

Pyrometers are now available which, in the hands of a reasonably bright boy who has been trained for a week or two, will give more consistently reliable results than the most skilled and experienced eye. Once convinced of this, the expert foundryman breathes a sigh of relief and turns his attention to other things.

Production Foundry Offers Greatest Field for Pyrometer Use

It is probably true that the pyrometer finds its sphere of greatest usefulness in the production foundry, where much the same castings are made day after day.

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The problem is to so gauge the temperature of the metal that the largest possible number of molds can be poured from a pot of metal without making scrap by pouring the first molds too hot or the last ones too cold. The number of molds which can be poured successfully depends upon the pouring range of the casting and the exactness with which the molten metal temperature is known.

By pouring range is meant the limiting temperatures between which the metal can be poured into sound castings which will have the desired properties. This range may be as much as 100 degrees Fahr. or more, or it may be as little as 40 degrees Fahr., depending upon the design of the casting and the properties required of it. Any casting which must be poured at an exact temperature within limits of less than plus or minus 20 degrees Fahr. is not designed for economical handling in the foundry. If such a casting must be made a liberal scrap allowance is necessary.

As an illustration, consider the case of a casting which can successfully be poured at any temperature between 2050 degrees and 2150 degrees Fahr If only one mold were to be poured it is obvious that almost anyone, given a little experience, could gauge the metal closely enough with the eye to pour sound castings. No great accuracy is required if one has a margin of plus or minus 50 degrees Fahr. But, for the sake of economy in handling the metal, a number of molds must be poured from the same pot; the greater the number the greater the economy. Assume that the metal in the pot cools at the rate of 20 degrees Fahr. per minute and that three molds can be poured per minute. Then, if pouring is started at exactly 2150 degrees Fahr., fifteen molds can be poured before the falling temperature reaches 2050 degrees Fahr. and the castings will all be good, so far as temperature is concerned. If, through inaccurate determination of the temperature, pouring is started at 2110 degrees Fahr. instead of 2150 degrees Fahr., and fifteen molds are poured, the last six molds poured will produce bad castings. Similarly, if pouring is started at 2190 degrees Fahr. the first six molds poured will be bad. If, in order to play safe, only nine molds

are poured instead of fifteen there is a considerable sacrifice of economy. Evidently it is highly desirable to begin pouring precisely at 2150 degrees Fahr., or as closely so as may be practicable. With a properly calibrated pyrometer in capable hands it is possible to do this within plus or minus 10 degrees Fahr. Nothing like such accuracy is attainable in any other way.

In the case of castings which have a pouring range of 40 or 50 degrees Fahr., and there are always some of these in almost every foundry, the pyrometer is even more valuable and necessary. The foundry superintendent, who formerly found it essential to give personal supervision to the pouring of such castings, is now relieved from an exacting and troublesome responsibility.

Extent of Use in Foundry

In our plant approximately 400 temperature readings per day are taken when the foundry is busy. The procedure is as follows: The metal is always taken from the furnaces at a temperature higher than is required for the work, in order that it may be cooled to exactly the desired temperature. In the case of the electric furnaces the margin of excess superheat is very slight since the temperature of the metal leaving the furnace can be closely predetermined; in the coke fires no such accuracy of control is possible and the superheat is commonly 100 degrees Fahr. or even more. The metal is taken to a skimming station, stirred and skimmed. It is then cooled, under the direction of the pyrometer operator, by stirring in gates or pigs until the temperature is supposed to be about 50 degrees Fahr. above the desired point. A reading is then taken and, based on this reading, the metal is cooled to the desired temperature, which is checked by a final pyrometer reading. Each pyrometer reading takes six seconds; the entire procedure, including stirring and skimming, is carried through in approximately one minute.

Readings Taken at Skimming Station

It will be noted that all temperatures are taken at the skimming station, rather than at the mold. The pyrometer man, who is a foundry employee, receives his instructions from the foundry

superintendent as to the work on the floor and the metal temperature required for each class of work. In giving these instructions the superintendent makes due allowance for the loss of heat during transportation of the metal to the molds. This allowance is the result of both experience and test and can be made quite accurately.

As the metal leaves the skimming station, the pyrometer man hangs a tag on the ladle trolley, showing in large figures the result of his final reading. The pouring boss, in deciding how many molds can safely be poured in any class of work, is governed entirely by the temperature report shown on the tag.

Alloys Vary in Fluidity

All of our alloys are held very closely to analysis. Composition ingot and other metals are purchased on rigid specifications and carefully checked to these specifications before being used. In spite of these precautions, we find that the pouring quality of the metal is not a constant factor.

The best pouring temperature for any given casting varies from time to time according to the quality of the metal which is being used, in spite of the fact that there has been no change in the analysis. For example, in starting a new lot of ingot we discover that the metal is more fluid than before and that it is necessary to reduce all pouring temperatures in order to avoid "burn in" and spongy castings. This variable is regulated by taking as a standard a casting which is in constant production throughout the year.

Suppose that the foundry has been pouring this casting at 2200 degrees Fahr. When a change is made from one lot of ingot to another, the first molds of this casting poured from the new mix are blown out and examined by the foundry superintendent or pouring foreman, who then decides whether a pouring temperature of 2200 degrees Fahr. is still suitable or whether a change of 20 or 30 degrees Fahr., up or down, should be made.

If a change is made with respect to this casting, a similar change is made throughout the foundry wherever this particular metal mix is being used. This works very satisfactory on the

general run of our work, where the pouring range is 100 degrees Fahr. or more. In cases where the pouring range is only 40 degrees Fahr., or thereabouts, it is essential that the metal used be very uniform, day in and day out. This uniformity can, of course, be accomplished whenever the results to be obtained justify the expense of doing so.

Lack of uniformity in the fluidity of composition ingot, scrap copper and the like is probably due to a variation in dissolved oxides and the presence of other impurities in various physical states, the nature of which cannot always be determined by chemical analysis.

Type of Pyrometers Used

The pyrometers used are of the exposed-couple, base-metal type, with low-resistance, portable meters. The tips are 19½ inches long and average better than 125 readings per pair. All pyrometers are checked twice a day in the foundry against a standard instrument. At the slightest evidence of inaccuracy the meter under suspicion is withdrawn from service and rechecked in the laboratory. Usually repairs and adjustments are made in our own laboratory but occasionally—about once in six months—the meters are returned to the makers for a thorough overhauling.

Precautions to Be Observed

In reading molten metal temperatures with an exposed couple a number of precautions must be carefully observed. A certain aptitude on the part of the operator is also required. Nine men out of ten can acquire the necessary skill without difficulty. An occasional man who may be selected as apparently qualified for the job will prove to be hopelessly unable to master the required technique. Two qualified operators should always be able to check each other within plus or minus 10 degrees Fahr., each using his own pyrometer at the same time in the same pot of metal.

Before taking a reading the metal should be skimmed clean. The tips are then immersed at the center of the exposed metal

surface to a depth of not less than three inches. The couple is held in this position until the meter needle comes approximately to rest, taking care to hold the tips as nearly motionless as possible and, above all, not touching the edge of the pot. The position of the needle at this point represents the temperature of the metal surface but the reading is not a reliable one since it cannot be checked within 30 or 40 degrees Fahr. The couple is then raised quickly until the ends of the tips are barely immersed. The tip ends, because of their deeper immersion, are at a temperature higher than that of the metal surface, and bringing them to the surface causes the meter needle to rise anywhere from 20 to 100 degrees Fahr. The type of meter used is practically "dead beat" and the highest point reached by the needle, before it starts to settle back, is taken as the metal temperature. This reading can be checked time after time and, according to our experience, consistent readings can be obtained in no other way.

Before taking another reading a coarse file must be run over the surface of the couple to remove oxide and congealed brass. The couple need not be perfectly clean but should present a fairly large surface of bright metal. The tips must be of equal length and if one has melted away more than the other the end of the longer tip should be cut off.

Savings Attributed to Use of Pyrometer

Under our conditions temperature control can definitely be credited with tangible savings amounting to at least five times the overall cost of maintaining the control. Less tangible advantages are numerous but difficult to evaluate in dollars and cents. In other foundries the savings might be proportionately more or less than in our case, but it is the author's belief that any foundry, jobbing or otherwise, of any size, no matter how small, will profit by the intelligent use of an up-to-date pyrometer.

Brass Foundry Pyrometer Can Be Improved

Brass foundry pyrometry, in the present state of the art, is by no means so perfect as it should be. The use of an exposed

couple has the advantage of giving a consistent reading in six to eight seconds but the method is not so foolproof as might be desired. The use of a protected couple reduces variations due to the human element but, in our opinion, it takes far too long to get a reading. The constant checking of meters and couples is rather a nuisance; it is to be hoped that pyrometer manufacturers will soon be able to improve this condition. In spite of these drawbacks it can confidently be said that the use of pyrometers in the brass foundry is now not only practical but also highly profitable, and probably capable of nearly universal application.

Discussion

K. Marsh: I should like to ask how far apart you have your elements at the hot end. I should think there might be some possibility of the metal bridging over or the skin bridging over and causing a short above your surface unless you have them spaced.

H. M. St. John: The points are spaced I should say about half an inch. It isn't less than that; it might be a trifle more. We don't experience any difficulty. As a matter of fact, you could see it if it did happen. I will say that with the open end couple you will occasionally get a reading that you instinctively know is wrong, that is, a man who had experience can tell by the behavior of the needle that he is not getting a correct reading, and in a case like that he goes back and tries it again. That happens, however, so infrequently and can be detected so certainly that it is not really a troublesome matter. What may cause it I don't know. Using an open end cupola in the manner which it was first attempted to use it, that is, merely dipping the couple in the metal, leaving it there, then letting the needle come up and take a reading, sometimes gives very weird results. I have seen the needle go clear off a 2500 degree scale when you knew the temperature of the metal was not over 2100, and I have seen the needle go backward so that it hit the zero stop, due to some counter e. m. f.

J. M. Robertson: I should like to ask Mr. St. John how high you bring the heat up in the furnace on the 88, 10 and 2 when you are pouring.

H. M. St. John: We pour so little 88, 10 and 2 that I can't answer that from my experience in our own foundry. I would say in any case that it depends altogether on the casting you have to pour. Eighty-eight, 10 and 2 I believe should be poured as cold as you can pour it and get away

with it. How cold that is depends upon the casting, how you have it gated, and a number of other things. We use it very little.

J. M. ROBERTSON: I was wanting to get at how hot you melt it; do you bring it up to twenty-three or twenty-four?

H. M. ST. JOHN: I don't think we ever bring 88, 10 and 2 that high, probably not over 2200 at the outside. Some of our other alloys we do bring as high as 2400 in the pit fires where we don't have as good control as in the electrics. In the electrics we are able to avoid a lot of superheat because we can predetermine the temperature of the metal. We can bring metal out pretty consistently not over fifty degrees beyond the temperature we want to pour. Our experience in the pit fires has been that we have to hit around a hundred degrees above. We don't ever pour 88, 10 and 2 in castings that have to stand pressure, so that really my experience in that line doesn't meet your case.

R. W. MAYER: With reference to a high or low-resistance instrument, what varying lengths of thermocouple do you use? You start with what length?

H. M. ST. JOHN: About a 20 inch length and use it down to about 9 inches.

R. W. MAYER: Did you ever get any comparative readings in the same pot with two operators, due to the difference in the resistance of the circuit with a low-resistance instrument with those different lengths of couples?

H. M. ST. JOHN: We don't find that that makes any difference. You see our tips are pretty heavy. We use a quarter inch alumel and an eighth inch chromel, and the resistance of that is not so very great. The natural tendency of the operator is to dip the long tips when they are new more deeply than he does his short tips when he is getting down pretty close to the end, which also tends to compensate to some extent.

W. F. ROESER: I should like to have Mr. St. John emphasize the importance of keeping the tips of these open end thermocouples clean.

H. M. ST. JOHN: That is mentioned in the paper. I may not have mentioned it here. We file off the tips after every reading with a rough file. That doesn't mean that we get the tips clean, it isn't necessary to have them spotless; it can't be done, because after they have been used a couple of times they are all pitted and you couldn't get into the pits with a file, but you do have to have a fair area of clean, bright metal. In other words, you have to get your high spots all filed off clean before you take your next reading. If you let the tips get gummed up with slag and oxide, your reading won't mean anything.

L. M. MARSHALL: Mr. St. John referred to some of our objections to the open end couple. We use this method he suggests, using a low resistance before we use the modified couple. As he said, we have found that quite good results can be obtained by a man skilled in its use. There were still very many cases where the pyrometer reading had to be modified by the judgment of the operator, and our feeling was that if we were going to swing over to a mechanical means of measuring the temperature it would be much better if we could rely on the mechanical instrument instead of combining both judgment and measuring instrument, and that was added to by the fact that our foundry wanted to cut down the cost on temperature making and insisted on giving us cheap labor and frequent change in labor.

The job in the foundry now of taking temperatures is usually the initial job of the new man coming in and it is being done successfully with the closed end couple.

E. F. HESS: I should like to ask Mr. St. John about keeping both ends of his couple the same length. Do you notice any variation if one end is a little longer than the other?

H. M. ST. JOHN: The alumel tip always wears away faster than the chromel tip, despite the fact that it is of larger gauge. It is necessary to keep them very closely the same length. If you have your chromel tip projecting possibly an inch and a half or two inches beyond the alumel tip, you have difficulty in getting a good reading. We simply cut off the chromel to keep them within a half inch in length throughout the life of the couple.

MR. ROBERTS: Can you give me an idea of the average number of immersions you get on ordinary red metal in the total life of the couple?

H. M. ST. JOHN: The total life of the tips at an average temperature of around 2200 or a little above, starting with 20 inch tips, is from 125 readings up, getting down to about a nine inch length, which we consider as short as is practical.

W. F. ROESER: In a survey of eleven foundries using the open end alumel and open end couple such as Mr. St. John is using, I found that the thermocouples average fifteen readings per inch.

Pyrometer Control in a Brass Foundry

By Andrew S. Hall,* Philadelphia, Pa.

Pyrometers—are they practical in the brass foundry? This for a long time was considered a moot question. The average foundryman believed practical experience constituted sufficient knowledge for the production of good castings.

The new era, brought about by the introduction of machinery into the foundry, prepared the minds of foundrymen for new methods in the melting and casting of the metal. Competition and the demand for quantity production required low production cost. To accomplish this end required the reduction of losses caused by bad castings. In some instances, this brought the chemist and metallurgist, either directly employed or in a consulting capacity, into the non-ferrous foundries. Scientific methods required definite knowledge of every operation in the production of castings.

Close supervision over the mixing of metal received first consideration. This is necessary in order to insure the proper physical properties of the metal. Quite naturally, the technical man attached considerable importance to temperature control of the metal and thus pyrometers were given a permanent place in the scheme of things in the modern foundry.

The success of pyrometer control in the brass foundry of a large electrical manufacturing company in the Philadelphia district is typical of what can be accomplished when intelligent supervision is applied. The recital of experiments and experiences at this particular foundry will do much to dispel the skepticism of some foundrymen who have condemned pyrometers in general because their own experiences in particular have been unsuccessful. Research on the part of the pyrometer manufacturer, together with the practical knowledge of the experienced foundrymen, is a combination that has overcome many of the foundrymen's difficulties.

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*Thwing Instrument Company.

Experiments with Various Types of Pyrometers

What type of pyrometer to use was quite a serious matter to be decided and many experiments were made before a reliable, practical and successful pyrometer was secured.

The optical pyrometer was tried for a time, but with such poor success that it was finally discarded as being impractical for temperature readings of non-ferrous metals. Especially was this true on account of the time factor. In taking a temperature reading, an immersion tube was inserted into the metal and the optical pyrometer sighted at the inside of the immersed tube. As a result of so much time being consumed until the immersion tube could assume the temperature of the metal and a reading taken, the metal cooled too much.

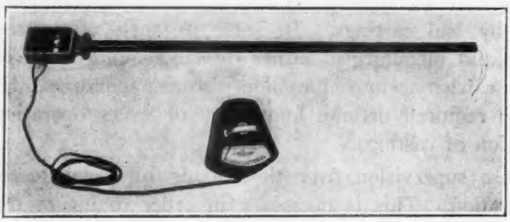

FIG. 1—PYROMETER COMPLETE

After experimenting with various makes of base metal pyrometers, a quick acting portable and extensible pyrometer was selected as being the most practical pyrometer for foundry use.

This pyrometer provides a reliable and inexpensive means for quickly taking temperature readings of brass, bronze and aluminum. A brief description of the pyrometer will serve to give prominence to the features which appeal to foundrymen.

Description of Pyrometer

This pyrometer consists of a direct reading portable indicator and an extensible magazine thermo-couple. The portable indicator is contained in an aluminum case and is provided with a handle so that it is very easily carried about the foundry. It is calibrated for a temperature scale range to 2400 degrees Fahr.,

FIG. 2—TAKING TEMPERATURE READING OF METAL IN THE PIT FURNACE

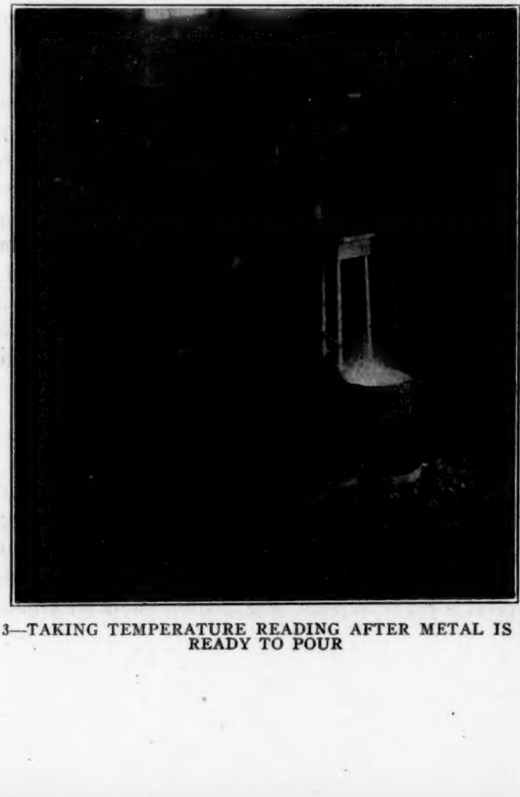

FIG. 3—TAKING TEMPERATURE READING AFTER METAL IS MADE READY TO POUR

the temperature graduations being in 20 degree divisions and easily readable to 10 degrees. The thermocouple consists of two steel tubes, which are insulated throughout their entire length with porcelain insulators. These two steel tubes are fastened into an aluminum head in which are mounted two spools of thermocouple element wires. In operation these wires are drawn down through the tubes and extended to a length of about 12 inches; the ends of the wire are then twisted tightly together to make the hot junction of the thermocouple. No weld is necessary.

Quick Acting Feature

In order to take a temperature reading the twisted junction of the wires is immersed in the metal. The wires being small in diameter (approximately 1-16 of an inch) they immediately assume the temperature of the metal and a temperature reading on the indicator is quickly secured in 10 seconds. A number of readings can be taken with the same junction, depending upon the alloy. After several temperature readings, the junction may be destroyed and all that is necessary is to retwist the wires, which can be done in about one minute. The junction can be renewed several times before another supply of wire need be drawn out from the tubes. The thermocouple is furnished with a supply of element wire, consisting of 50 feet of positive and 50 feet of negative wire. With this extensible feature, there is really a thermocouple 50 feet long with the advantage of being able to renew the thermocouple by making the hot junctions whenever necessary; this is done quickly because no weld is required. The supply of wire can be renewed whenever necessary at a very nominal cost. Fig. 1 shows the pyrometer complete, including the portable indicator with 10 feet of flexible leads and the extensible thermocouple.

Frequent Temperature Readings

The furnace equipment at this foundry consists of seven natural draft pit furnaces, one electric furnace, one stationary oil furnace and one pit type oil furnace. Temperature readings of the metal are taken while the metal is in the furnace and again when the pots are drawn from the furnace and the metal is ready to pour. Fig. 2 shows how the temperature

readings are taken with the pyrometer while the metal is in the furnace and Fig. 3 shows a temperature reading being taken when the pot has been drawn and the metal is made ready to pour. The foundrymen do not resent this pyrometer because with the quick acting feature no loss of time is occasioned when taking temperature readings.

Definite Pouring Temperatures

It is now the practice in this foundry to take temperature readings both while the metal is in the furnace and when it is on the floor ready to pour. For every mixture of metal definite pouring temperatures are specified. Table 1 gives some approximate pouring temperatures of various alloys which for general

Table 1

Table of Approximate Pouring Temperatures

All Temperatures are in Fahrenheit Scale.

Metal	Mixture	Degrees Fahr. for General Work	Degrees Fahr. for Castings Light	Heavy
Aluminum	Pure	1,400		
Aluminum	Alloy	1,300	1,300	1,250
Red Brass	85—5—5—5	2,000	2,150	2,000
Red Brass	82—4—6—8	2,000	2,100	1,950
Yellow Brass	15 to 20 per cent Zn.	2,000	2,100	1,950
Phosphor-Bronze	80—10—10	1,950	2,000	1,900
Manganese-Bronze	....	1,800	1,950	1,780
Acid Resisting Bronze	87 Cu.—7 Sn.—6 Zn.	2,150	2,100	2,000
Bronze	88 Cu.—6 Sn.—4 Pb.—2 Zn.	2,000	2,100	2,000
Bronze	{70 Cu.—20 Pb.—6 Sn. other metals 4 per cent}	2,150		
Bronze	87 Cu—8 Sn—5 Zn	....	2,050–2,100	1,900–1,950
Nickel-Bronze	84 Cu.—10 Sn.—2 Zn.—4 Ni.	2,100	2,150	2,100
Gun Metal	88—10—2	2,050	2,100	2,000

foundry work have been found very useful. Of course, practical experience and local conditions will sometimes determine when variations from these temperatures should be made.

The Pyrometer at Work

The variety of the work in this foundry can readily be appreciated, castings range in size from ¼ of a pound to 4,000 pounds. A considerable quantity of aluminum is cast in addition to brass and bronze.

One very interesting instance of exact temperature control is in the pouring of aluminum alloy manifolds for gasoline engines. The pouring of aluminum alloy should be done at the

lowest possible temperature at which the metal will run and completely fill the mold. A temperature of 1250 degrees Fahr. is generally satisfactory. A low pouring temperature is particularly important for aluminum alloy castings because of the high specific heat of the metal. If poured at a high temperature, the metal in cooling heats the mold so hot that the rate of cooling is very slow, which results in a coarse grain and weak metal. Aluminum alloy castings are always stripped as soon as they are set, to prevent cracking. A number of tests were made in casting these manifolds with the following results: at 1260 degrees Fahr., the castings cracked; at 1220 dergees Fahr., the metal would not run sufficiently to fill the mold. At exactly 1240 degrees Fahr., the metal is fluid and exceptionally good castings are made. The effect of high pouring temperatures on the strength of

Table 2

Table Showing How High Pouring Temperatures Affect the Strength of Aluminum Castings

Temperature Degrees Fahr.	Tensile Strength Pounds per Sq. In.
1,200	20,000
1,250	19,500
1,300	19,200
1,350	18,500
1,400	18,000
1,500	17,500
1,600	16,000

aluminum castings, is clearly shown by Table 2. These data were compiled by Dr. Paul D. Merica, of the International Nickel Company, and tests have proven it very valuable. When working to very close temperature limits as just described, it is advantageous to use a table or solid foundation of some sort on which to rest the pyrometer.

Another instance where the pyrometer proves especially valuable is in the casting of large air pump runners for turbine condensers weighing 3,000 pounds made of an 88 copper-12 tin mixture. To make these castings, it is necessary to draw the pots and pour the metal into a large pouring ladle, then pour the metal into the molds. The best pouring temperature for these runners was determined at 1900 degrees Fahr. Of course, the metal was brought to a higher temperature in the furnace and when sufficient metal was in the large pouring ladle, the metal was allowed to cool. Several temperature readings are taken in quick suc-

cession, but this is very easily done because only 10 seconds is required to secure each reading. When the pyrometer indicates 1900 degrees Fahr., the mold is poured and very good castings have always been secured.

The casting of bronze water pump runners for turbines of the same composition also presented some difficult complications. These water pump runners weigh approximately 1800 pounds and to lose one of these castings means a loss of considerable money. Fig. 4 shows a number of these castings, all poured at definite temperatures. Making the molds alone is an expensive item and if the casting should prove a failure the loss in remolding and re-

FIG. 4—GROUP OF CASTINGS, ALL POURED AT DEFINITE TEMPERATURES

melting is large. Previous to using this pyrometer the casting of these water pump runners was a problem that caused a great deal of worry. Now with the quick reading pyrometer, the loss of a water pump runner casting is unthinkable. The savings resulting from the use of this pyrometer in the casting of these water pump runners alone have been sufficient to pay many times over for the two pyrometers which are used in this foundry.

The success of pyrometer control in this large foundry is being duplicated in other foundries, some large, some small. Results do not depend upon the size of the foundry, but rather upon the will to accomplish best results with modern means. The moot question is now undebatable. Pyrometers are now as much a part of the non-ferrous casting business as the foundry itself.

Discussion

W. F. Roeser: May I ask Mr. Hall if he uses copper lead or extension lead with his pyrometer?

A. S. Hall: This is simply a copper lead.

W. F. Roeser: How do you direct the variation in the handling of your instrument?

A. S. Hall: We do not make any corrections for the cold end temperature. We have found it to be the case generally, where a temperature reading of the metal is taken the surrounding atmospheric temperature is such that the cold end error makes no particular variation. I have seen this pyrometer checked against a potentiometer in a certain foundry. The cold end error was eliminated with this potentiometer. As a result of the test they found that the potentiometer lagged 50 degrees behind this pyrometer all the way up to the final pouring temperature of manganese bronze. They poured at 1800 degrees, and at 1800 degrees the potentiometer and our millivoltmeter pyrometer agreed.

W. F. Roeser: All thermocouples have a cold end whether you use a potentiometer or indicator tip. I visited several foundries during August and July, and several times I saw a temperature of 80 degrees, most of them around 100 to 120, in the foundry.

H. M. St. John: I spoke of checking within plus or minus ten degrees Fahr. with two different operators. I might say we couldn't hope to do that if we didn't adjust the zero point of our meter to correspond with low temperatures.

R. W. Mayer: Mr. Hall seemed to express an idea that is somewhat prevalent among pyrometer users; namely, that the potentiometer is not affected by the cold junction thermocouple. The potentiometer is one means of measuring the electromotive force produced by the electric thermocouple and in no way connects with the cold junction of the thermocouple. It is possible to obtain an automatically compensated millivoltmeter that doesn't compensate with those by using the extension thermocouple to the meter. That has some objection in that it quickly fluctuates, that is, if the temperature at the meter changes, the meter itself cannot keep up with those changes. For example, if a hot ladle is brought in close proximity to the instrument, naturally the surrounding temperature will change very quickly and the compensation of the instrument cannot react to that immediately, but it is far more satisfactory than not taking it into account at all.

A. S. Hall: Perhaps I didn't make myself perfectly clear. In this particular test with the potentiometer they used cold end extension leads from the thermocouple to the potentiometer, which was equipped with a

compensator. I just want to point out to you, to show the general condition of this particular test, that it was the last week in December when the outdoor temperature was cold. The furnace was located near a door which was open, so that if there should have been any particular temperature which would have influenced the cold end temperature it would have happened right there at that particular place, yet the variation in the pyrometer readings was decided up until the last reading, which was the final pouring temperature, showing that the presence of the heated metal or the furnace had so tempered the atmospheric room temperature that it had no effect upon the portable pyrometer cold end temperature. This pyrometer, of course, is equipped with a zero adjuster, and if it happens to be a particularly hot day or a cold day it is easy to adjust manually, the zero setting of the instrument.

The Use of Pyrometers in the Casting of Non-Ferrous Metals

By R. D. Bean,* Philadelphia, Pa.

During the past few years considerable progress has been made in the casting of non-ferrous metals, principally through the study of melting and working temperatures. The manufacturer of today constantly faces the problem of meeting increased labor costs and a smaller margin of profit in addition to the keen competition from other concerns in the same business who are continually improving the quality of their product through improved methods of manufacturing. This means the elimination of waste and guesswork, increased efficiency in production, and a constant search for better methods and better materials. The measurement and control of temperatures is a vital factor in practically every industry and no less important in modern foundry practice.

The progressive foundry man has eliminated guesswork and has substituted in its place the accurate measurement of melting and pouring temperatures. This does not imply that good castings cannot be made without the aid of a pyrometer, but miss-runs are not a necessary evil, and there is always room for improvement in the size of the scrap pile. Under certain operating conditions a pyrometer equipment will pay big dividends, and this has been demonstrated so often, even in the small foundry, that this statement requires no further discussion to substantiate it. This is particularly true in a foundry making a variety of castings where different metals are poured every few days. Errors in estimating temperatures are bound to occur with resultant loss in production from defective castings, and experience will gradually convince the foreman that a pyrometer is more accurate and dependable than the eye.

Selecting the Proper Equipment

The simplest type of pyrometer equipment for measuring molten metal temperatures consists of a portable bare wire thermocouple, with suitable handle, connected to a small portable indicat-

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ing instrument with about 3 feet of flexible lead wires. A combination frequently used consists of a chromel-alumel thermo-couple and an indicating instrument with a range of 0 to 2600 degrees Fahr.

The instrument should preferably be a high resistance type, so that changes in the length of the couple, or in its cross section, will have a negligible effect on the accuracy of the readings. This type of instrument was almost unknown a few years ago, but the instrument designer of today can produce a portable indicator of the above range, having a total resistance of about 600 ohms, which will stand up surprisingly well and maintain its accuracy if a reasonable amount of care is used in handling it. The current required to deflect the pointer to full scale value is only .00008 amperes and the pointer will follow the changes in the couple temperature as fast as the changes occur. The weight of the movable coil is so small that there is practically no swinging of the pointer before coming to rest, and a reasonable amount of jarring will have no effect on the pivots and jewelled bearings.

The wires connecting the instrument to the thermo-couple should be of suitable material to extend the cold junction of the thermo-couple to the instrument binding posts. This will eliminate errors due to changes in temperature at the cold end of the couple which is frequently exposed to the radiant heat from the metal, particularly when readings are taken with the couple extending vertically downward into a ground level furnace. Portable instruments are available with automatic means for compensating for changes in the cold junction temperature when the cold junction is extended to the binding posts of the instrument. If the instrument is not automatically compensated, corrections must be made in the reading whenever the temperature at the cold junction is different from the temperature at which the instrument was calibrated. This temperature is usually indicated on the scale of the instrument by a suitable mark. On instruments having evenly graduated scales, without automatic compensation, the pointer should be set to a point on the scale corresponding to the temperature of the room. This adjustment is made by means of a zero adjuster screw and must be made when the thermo-couple is disconnected from the instrument.

The thermo-couple is usually constructed in such a way that the tip is easily replaceable. The welded hot junction will last for a long period of time in metals like pure aluminum or copper, but will dissolve rapidly in certain alloys containing zinc. The couple will continue to give accurate readings, even after the welded junction has dissolved, leaving the two wires separated, providing they are close together and there is no accumulation of metal or slag on the wires. In another construction for molten metal measurements, the couple wires are wound on reels in a magazine, and the hot junction is renewed by drawing out a few inches of the wire and twisting the two ends together. A portable equipment with bare thermo-couple makes a handy type for taking quick readings from a crucible just before pouring. From seven to ten seconds are required for each reading. This same type of equipment is also suitable for taking readings of the melting temperature of aluminum in a tilting crucible furnace.

On some applications it is convenient to use a wall type of instrument which may be either indicating or recording. The scale of the instrument is drawn with large figures easily read at a distance of several feet. The instrument is located near the melting furnaces or at some convenient location where several crucibles can be reached within a radius of fifteen or twenty feet. A recording instrument makes a permanent record of the temperature of each pouring as well as the number of pourings.

Some Typical Applications

The value of a simple type of portable indicating equipment is illustrated in the case of a concern manufacturing aluminum pressure cookers. The miss-runs were averaging around 15 per cent and considerable difficulty was experienced with leaky castings. The large thin-walled molds presented a difficult problem and several sizes were being made. The aluminum had to be hot enough to fill the molds, and yet give smooth castings that would hold pressure. After using a portable pyrometer equipment, the man worked out the proper temperatures for each different casting according to the size and thickness of the walls. For several years since, the miss-run losses have been less than

1 per cent and the number of leaky castings due to excessive shrinkage is negligible.

A foundry pouring bearing metal worked out a novel arrangement with a recording pyrometer. The instrument was mounted on the wall and a thermo-couple was suspended from an overhead beam; the cable running over a pulley and having a counterweight slightly heavier than the couple. As each crucible was pulled, the thermo-couple was lowered and a reading taken. The thermo-couple then was released and swung up out of the way until the next crucible was ready. By examining the chart record made by the recorder, the foreman knows the temperature of each pouring and the number of pourings made each day, also the time at which each pouring was made. The bronze alloy used in this foundry was run at about 2100 degrees Fahr., and the replaceable tips dissolved quite rapidly. It was necessary to use from two to three replaceable tips per day. Experiments were made using a metal protecting tube sold under a trade name, and this material lasted for two hundred or more immersions. The metal protecting tube should have as thin a wall as practicable so as not to increase the time lag appreciably. This particular protecting tube is drilled from solid rod and the wall thickness for a tube 10 inches long is preferably from 1/16 of an inch to 3/32 of an inch thick. In order to maintain a uniform wall thickness these tubes are drilled on a rifle-drilling machine. The lag with a protecting tube of this type varies from 45 seconds to 2 minutes, depending upon the diameter of the tube and the wall thickness. A one minute lag with a large crucible or tilting furnace is not objectionable to the men, and a thin-walled tube is likely to have as long a life as a thick-walled tube owing to the shorter period of immersion to obtain a reading.

Recording pyrometers have also been applied quite successfully to tilting ladles for molten copper, to record the temperature of the copper as it goes into the ladle for transfer to the molds. For this application a platinum thermo-couple is used, having a primary protecting tube of porcelain and a secondary tube of chromium iron alloy. A thermo-couple of this construction has an appreciable lag, but owing to the size of the ladle and the time taken to fill it, the lag does not slow up the process. The couple is

installed horizontally through the side of the ladle, partly imbedded in the cement lining at the bottom, so that the top surface of the protecting tube is exposed to the molten copper.

Automatic Control

Automatic temperature control has been applied to oil-fired stereotype pots with marked success and considerable saving of time. The thermo-couple is permanently installed in the pot and the pyrometer is equipped with electrical contact tables which can be set at the desired operating point by means of an external adjusting screw. The contact tables close the circuit to relays which in turn operate a small electric motor geared to a valve which controls the amount of oil or gas fuel. Only one skimming of the metal is necessary and the temperature can be held consistently at 600 degrees, finishing the run with a pot full of metal at the right temperature. When the pot is not in use, the index on the control pyrometer is lowered to hold the pot at a lower temperature until ready for the next run. In newspaper work where time is a vital factor, this equipment has been a real asset.

When one considers the progress made in the last few years in the automatic control of temperatures; the improvements in design and the materials available from the research work of the metallurgists, it becomes apparent that a step into the future will disclose numerous applications of automatic temperature control in the casting of non-ferrous metals, and ideas now in the minds of research workers will become common every-day practice in the progressive foundries.

A Thermo-couple for Ladle Temperatures of Brass

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The advantages of temperature control in the foundry have received general recognition of late. It is no longer a question of the advisability of measuring the temperature of the molten metal, but the problem is rather to find a reliable method for use in the plant. The present paper concerns itself with a modified thermo-couple that has been found to give satisfactory service with red brass. It is intended to confine the discussion to a description of the thermo-couple and the service it has shown it will give.

In the manufacture of small brass castings there are at least two distinct points at which the temperature may be measured; first, in the melting furnace, second, in the pouring ladle. While furnace temperature is important, tests and experience have indicated that the temperature of the metal entering the mold is even more vital. The work described in this paper was directed toward securing some means of measuring the ladle temperature quickly and accurately.

Open End Thermo-couple Has Defects

The open end thermo-couple has been in use for some time for just that purpose, but all users and most pyrometer salesmen, even, will admit that such a couple is faulty. To be specific, it has three major defects. First, the slag on the metal coats the thermo-couple wires and interferes with the temperature measurements, sometimes completing the thermo-couple circuit outside of the metal. Second, when using the open end couple the needle of the indicator generally fluctuates, making it difficult to determine the exact reading. Third, at its best the temperature measured is that of the surface of the metal which may differ appreciably from that of the interior of the ladle.

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Special Thermo-couple Developed

In the endeavor to develop a more satisfactory means for measuring the temperature many different instruments and thermo-couples were investigated. The thermo-electric pyrometer system with a millivoltmeter indicator was adhered to in general, however, as being the most practical apparatus for use in the hands of unskilled labor under foundry conditions. Open end couples with various refractory coatings, a number of different kinds of protecting tubes, and other means suggested by pyrometer manufacturers were tried out in seeking a more reliable method for temperature measurement, all without success. It became evident, therefore, that the improvement sought could only be secured by special development work.

A protection tube that would not introduce too great a lag in the temperature readings and still have a reasonable life in service seemed an obvious way out of the difficulty. Work was accordingly inaugurated with that in mind. It was found that ferro-alloys of high chromium content offered quite remarkable resistance to the attack of molten brass. Consequently such alloys were used for the thermo-couple tips described here.

There were two qualifications that had to be met in order to secure a quick reading couple. First, the mass of the protection tube must be as small as possible. Second, there should be the very minimum of thermal insulation between the hot-junction of the thermo-couple and the molten metal. The use of a thin protection tube, which would form one element of the thermo-couple, suggested itself as a means of meeting these requirements. An insulated wire leading through the center of the tube and welded to its closed end would serve as the other element of the thermo-couple. This equipment was made and found to work. It was discovered, however, that small counter electromotive forces were developed, due probably to differences in temperature of the surface and interior of the molten metal, that made the temperature readings uncertain by 20 or 30 degrees Fahr.

To overcome this difficulty it was necessary to use the two-wire couple and have the outer tube serve as a protection means only. The single wire trial had shown, however, that quick

readings could be secured in that way; probably because the hot-junction was right in contact with the molten metal. It was decided, therefore, to keep this feature in the two-wire modification. Such a couple has worked satisfactorily from the start and with minor improvements is the type now in use.[4]

Description of Special Couple

Fig. 1 shows a longitudinal section of the thermo-couple tip now in use. It will be seen that the piece consists essentially of the chromium alloy protecting tube (A), in which is inserted

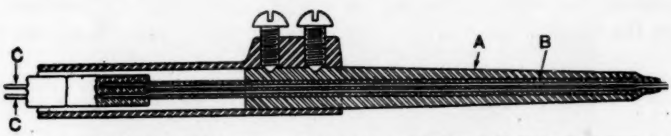

FIG. 1—THERMO-COUPLE TIP. A, ALLOY PROTECTION TIP; B, REFRACTORY INSULATOR; C, THERMO-COUPLE WIRES

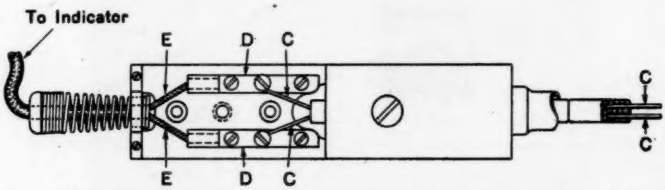

FIG. 2—THERMO-COUPLE HANDLE. C, THERMO-COUPLE WIRES; D, BRASS CONNECTORS; E, THERMO-COUPLE LEAD WIRES

the two-hole refractory insulator (B). The 16 gage chromel-alumel thermo-couple wires (C) pass through this insulator to the small end of the protection tube, where they enter a smaller hole in the end of the tip. These thermo-couple wires, at the tip, have been flattened out with a die so that each forms a half circle and together they just fit the hole in the tip of the protection tube. This tip is then swedged down against the wires, preferably by means of a die, thus clamping the wires together and closing any opening through which the molten metal might

[4] Patents have been applied for on this thermo-couple.

enter. Better results have been obtained with such a junction than were secured either by twisting the wires or welding them at the tip.

The thermo-couple is then mounted in a handle which consists of about two feet of twenty-two gage, five-eighths inch diameter, seamless steel tubing with a wooden hand grip. The protection tip is fastened into one end of the seamless tube by means of the two screws shown in Fig. 1. The thermo-couple wires, previously strung with refractory insulators, lead through the tube to the wooden hand grip shown in Fig. 2. The cap has been removed from this piece to show the method of connecting the wires. The thermo-couple wires (C) are fastened to the brass strips (D) by means of screws. These brass con-

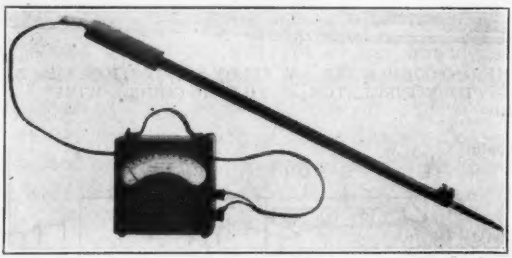

FIG. 3—THERMO-COUPLE ASSEMBLY WITH PORTABLE INDICATOR

nectors are permanently attached to the wooden handle and have the chromel-alumel lead wires (E) soldered to them. The lead wires (E) go either to the indicator or to the cold junction box. The spring coil on the end of the handle serves to protect these lead wires from severe bending at that point. Fig. 3 is a photograph of the complete assembly connected to a portable indicator.

As has been stated, the thermo-couple is in direct contact with the protection tip. This contact cuts the time required to reach temperature and does not interfere with the accuracy of the reading, since the thermo-couple is otherwise completely insulated from the protection tube and the circuit is consequently not completed. In practice a protection tip and thermo-couple

are assembled and kept in reserve. When the tip in use burns through, it is readily replaced by the spare part. This is accomplished by merely loosening the two screws that hold the protection tip in the end of the steel tube and unfastening the thermo-couple wires from the brass connecting strips in the handle. The worn out tip and couple are then taken out and the new unit slipped in and fastened.

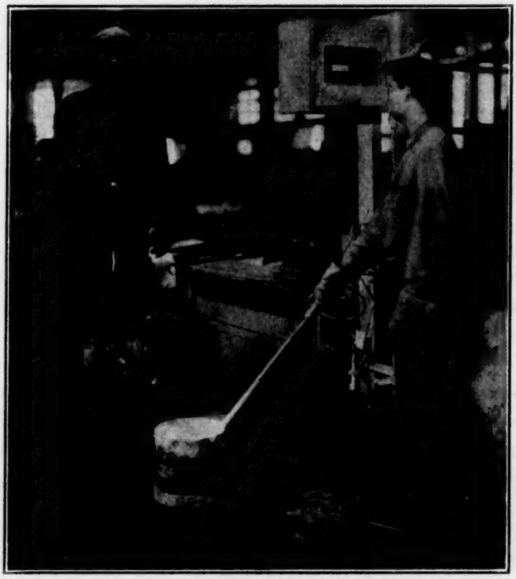

FIG. 4—MEASURING METAL TEMPERATURES IN THE FOUNDRY USING A STATIONARY INDICATOR

Method of Using Couple

Having described the construction of the thermo-couple, a few notes on its use will be included. It may be connected to either a portable or a stationary indicator, but the latter is more accurate and gives less grief in service. A permanent installation of a high-resistance, millivoltmeter-type indicator, mounted on a rigid support, has proven very satisfactory. Such a set-up neces-

sitates routing the ladles of metal to the pyrometer station, but that scheme has worked better than carrying the portable indicator to the pots. An added convenience can be secured with the high resistance indicator by having two thermo-couples connected to the instrument through a double throw switch so that a spare couple is always at hand. Fig. 4 shows a stationary indicator unit in use in the brass foundry.

In practice the thermo-couple is immersed in the molten metal for about three inches, stirring constantly with the tip. Moving it in this way cuts the time required to reach the metal temperature by about three seconds. The indicator pointer is watched and as soon as it comes to rest the reading is made. It requires around twenty seconds for the thermo-couple to come to temperature from a cold start. This interval increases but slightly with use. After each immersion the hot tip is gently wiped on a wire brush to remove the adhering slag. Care must be exercised at this point not to break the tip, as it is relatively fragile at the high temperatures. For the same reason, the thermo-couple should be so supported when not in use that there will be no chance for its weight to rest on the tip.

Experience has demonstrated the serviceability of this thermo-couple. Records of the tips used in the foundry show that with red brass, poured at 2000 to 2150 degrees Fahr., the average life of the tip is more than 800 immersions. When the pot temperature reaches 2300 degrees Fahr., however, the life of the tip is quite short; nor will it resist the action of phosphor bronze. On the other hand, trial runs in copper, yellow brass, and aluminum bronze have indicated the practicability of its use with these metals.

Summary

A modified thermo-couple has been described which makes it possible to quickly and accurately measure the interior temperature of the metal in a ladle. It can be successfully used in the brass foundry with unskilled help on temperatures up to 2300 degrees Fahr.

Discussion

H. L. Parr: How long does that tip last?

L. H. Marshall: Our records show in the foundry we have been getting an average life during the last six months of around 800 immersions.

W. F. Roeser: Mr. Marshall and Mr. Grubb state in their paper they noted a fluctuation in the couple when using the open end. Have they tried welding these tips to see if it would not steady the reading to a considerable extent?

L. M. Marshall: Welding has been tried but the weld burns off so quickly that the couple is not in use for a very long time before the weld is gone and it introduces a considerable expense of time to keep welding the couple, so the usual procedure of the foundry is to go ahead and use it whether it is welded or not.

H. M. St. John: Mr. Marshall mentions the fact that the tip is not suitable for phosphor bronze. Does that apply as well to phosphorized red brass?

L. M. Marshall: Our experience is that with phosphorus around a quarter of one per cent and in that vicinity the phosphorus alloy attacks the tip.

H. M. St. John: I am talking about percentages around less than one-tenth of one per cent.

H. M. Marshall: Our experience has to do with alloys to which a quarter of a per cent has been added and those alloys to which phosphor copper has been added merely as a deoxidizer. In the case of the deoxidizer it doesn't affect the tip but in the other cases it does.

W. Kosicki: In bronze bushing casting what couple would you use?

L. M. Marshall: In our case we have still held to the open end couple because of the attack on the metal.

Chairman N. K. B. Patch: In your experience with the phosphor bronze attacking it have you tried other protection tube with a view to correcting that at all? Have you any promise of anything of that kind?

L. M. Marshall: We have not gone into the phosphor bronze end of it so very much because in our case we were striving to put the pyrometer in use in our foundry and the percentage of phosphor bronze is very limited and only a minor problem with us, so we haven't given very much consideration to that end of the problem.

Visual Judgment of Non-Ferrous Metal Temperatures

By R. R. Clarke,* Erie, Pa.

Aside from the mensurating instrument, the determination of liquid metal temperatures is a product of the senses collaborating the judgment. Of the five senses, only two (sight and feeling or touch) lend their promptings in making this determination.

In judging any temperature to suit any need, two things must be known and understood: first, the proper temperature itself and, second, the manifestations of the metal at that temperature. The first is purely a matter of judgment derived from the size, the bulk, the section, etc., of the casting to be poured. The second calls into play both the senses and the judgment and involves their concerted activity.

Most metal temperatures are judged by sight from the standpoint of either the color or the viscosity of the metal, or both.

Judging by Color

Different metals and alloys vary sharply in color manifestations and no well defined or uniform standard of comparison can be taken by which to judge them. That all metals and alloys whiten toward sunlight with advancing temperature is about the nearest to a general rule that can be stated. Some metals proceed from red to white, some from yellow to white, some from red to yellow to white. It is, therefore, clear that in judging by color each metal and alloy is a law unto itself and must be known in its details of peculiarity in order to exercise intelligent judgment on it. As a matter of illustration, a few common metals and alloys will be discussed, as follows:

Copper: Copper appears dull red at low liquid temperature and proceeds to a bluish white with temperature. Free of oxides at high temperature it is beautifully clear and limpid.

*Alloy Foundry, General Electric Co.

Aluminum: Aluminum in shadow appears white at low temperature, advances to red at higher temperature and assumes a pale orange white at extreme temperature.

Copper 85-Tin 5-Lead 5-Zinc 5: This metal proceeds with increasing temperature from a reddish yellow to a yellowish white, interspersed with a bluish tint. This bluish tint derives at temperatures where the zinc volatilizes, giving the zinc-volatilizing color.

Copper 88-Tin 10-Zinc 2: This mixture is reddish yellow at low temperatures, yellowish white at high, "waved" with brilliant tints of blue and purple and gold. These elaborating tints derive from the tin content, which exhibits these distinctions at high temperatures.

Copper 80-Tin 10-Lead 10-Phosphorus traces: This alloy is blood red at low temperature, advancing to white with rising temperature.

Copper 70-Zinc 30: This metal is dull yellow at low temperature, yellowish white at high temperature, flaring with brilliant bluish yellowish tints that are caused by the volatilizing zinc.

Regarding these different manifestations as stated, it might be noted that they represent those appearing in reflected sunlight, or in ordinary daylight shade. When the shade becomes abnormal, as on a dark day, the color varies preceptibly toward a lighter effect. Thus, different alloys appearing red on a bright, clear day will appear white at the same temperature on a dark, cloudy day. Another distinction to be observed is metal in daylight and metal at night in artificial light. The difference in appearance often leads to bad errors of judgment if not known and observed. In total darkness all metals and alloys of high fusing temperature take on a greater whiteness and brilliancy.

Fluidity Factor

Fluidity in its varying degrees is a consequence of temperature and, to a well developed and finely discriminating sense constitutes a safe and stable indication of temperature; viscosity of metal is therefore the real and decisive test, the most nearly scientific test to which judgment can address its determining

powers. It is freely used by some molders and as freely neglected by others, the difference representing largely natural aptitude along with prevalent practice at the time of learning the trade.

Viscosity can be determined both by sight and by feeling and the two taken together afford a check against each other by which the condition of the metal can be quite accurately judged. The hotter the metal, the more fluid: the colder, the more viscous, makes up the fundamental principle of the system. Fluid metal as against viscous metal exhibits many distinctions plainly marked. It looks thinner, its surface lies flatter, it hugs the walls of the crucible closer, it displaces more easily, its dross and impurities ride higher, easier, freer the surfaces; a solid immersed in it meets much less resistance, it flows faster, easier, cleaner. It adheres to congealing walls less tenaciously, etc. These and various other exhibitions can be discerned either by sight or feeling or both and the relative temperatures they indicate may be judged by them. The end of a skimmer bar pushed over a metal surface will indicate the viscosity of the metal by the resistance it meets, as will the behavior of the liquid metal coming to rest following the disturbance.

Of course, close study and experience, along with an appreciation of different specific gravities of different metals and alloys, are essential to enlightened application of the viscosity test and are ever to be reckoned with in connection with it. One of the first tests on the alloy copper 80-tin 10-lead 10-phosphorus trace, the author learned, was to immerse a skimmer bar in the metal bath, hold it there a second and withdraw it. When the metal dripped off the drawn skimmer like buttermilk, it was ready to pour that particular casting.

As a general rule, cold metal by its very viscous appearance to sight engages the very intuition of experience as to its coldness. To first glance it appears numb, lifeless, and molders often intuitively remark, "It has a dead look." When a metal, an alloy, or some ingredient of the alloy, has reached its boiling point, an iron skimmer bar immersed in the bath will record the agitation of boiling to the sense of feeling in the nature of a clicking or crackling sensation. This phenomenon is quite in

evidence in the high zinc-copper alloys and is frequently used as a basis of judgment in high temperatures of those alloys.

If a bar of solid metal free from protective coating be immersed in a bath of kindred metal at high temperature, the solid metal will melt and disappear rapidly. If the metal bath be lower in temperature the bar will melt and disappear proportionately more slowly. This furnishes the basis for another observation test on metal temperature.

Action of Metal in Sprues

When hot metal comes to rest in a sprue head, the time consumed by the metal in this head to completely solidify is quite extended. If coming to rest at a lower temperature, the solidifying period is perceptibly shortened. From this it is possible to derive a good check on temperature by observing the sprue head of a mold poured first among a number of molds to be poured from the same pot of metal.

By the hydrostatic principles, the static pressure of liquid metal in a filled sprue advances with the fluidity of the metal. If a sprue be filled with hot metal, the metal after filling the sprue will sink down in the sprue much farther than will colder metal. This may often indicate a severe swelling or sand-burning of the casting from too hot metal.

In his molding days, the author always prepared his first two molds for pouring especially for hot metal. He would then bring his metal on the warm side to these molds, pour them and note the time it took the sprue head to solidify as well as the depth of descent of the metal in the sprue. This furnished a basis for one of the safest and best tests and corrections on metal temperature to which, in all his experience, he ever resorted.

Phosphorus Influence

Regarding metal viscosity it might be noted in passing that alloys without phosphorus usually present a rather viscous and misleading surface appearance, due to the oxide film occasioned by the atmosphere on that surface. By viscosity the metal

therefore appears colder than it really is. If a little phosphorus be added, as is often done, the metal at once looks relatively hotter than it really is, in that the elimination of the oxide film reveals the metal in its actual under-mass state. This thinner appearance of a metal surface when phosphorus is added is sometimes erroneously assumed to indicate that the phosphorus raised the temperature of the metal. The proposition will not demonstrate and practice completely disproves the assumption. The most the phosphorus does is to clarify the surface by reducing the oxide scum, giving the surface metal a thinner, clearer appearance. The same appearance will exhibit under a layer of charcoal over the surface metal. Under extreme temperature, many metals and alloys become so oxidized as to appear "lumpy," "granular," "thickened," "viscous," etc. In this state of oxidation they are "lumpy," "granular," etc., just as they appear to be, but the condition is due to *excess* of temperature rather than *lack* of it.

When a filled sprue in solidifying swells up instead of shrinks down, the indication is that the metal is suffering from included gases and oxides and suggests either bad furnace practice or too high temperature in pouring the metal.

The foregoing are a few of the author's more prominent methods of judging metal temperatures. They might be augmented by many additional observations did time and space permit. They are, however, fairly representative and sufficiently inclusive, we hope, to meet the reasonable expectations of those who read this paper.

Pyrometry of Molten Brass*

By W. F. Roeser[1] and C. O. Fairchild[2]

Introduction

In many brass foundries today the pouring temperatures are being successfully measured, but only in a few of these are the measurements on such a routine basis that it is regular practice to measure the temperatures of nearly all the metal poured. The authors need not present any argument here, that the best practice in brass foundries calls for pyrometric measurements on practically every ladle of brass. Furthermore, there is no reason why such measurements should not be made since the success attained in a few progressive foundries is sufficient proof that there remains no serious unsolved problem in the art of measuring these temperatures.

Practice generally has settled upon some form of bare base-metal thermocouple and indicating meter, to the exclusion of optical or radiation pyrometers, although the optical pyrometer is used to some extent, and in a few instances a thermocouple protected by a refractory metal sheath is used. None of the thermocouple pyrometers now in use can be considered as the standard type nor are pyrometer manufacturers yet agreed as to which is the most satisfactory type for brass foundries.

While it has been amply demonstrated that careful control of pouring temperatures with pyrometers is much superior to dependence on the highly developed judgment of a foundryman, pyrometric control of these temperatures may always remain somewhat troublesome. One can scarcely hope to install a pyrometer permanently in the melting furnace with any degree of success or to find any substance which can be immersed for long periods even in a low melting point brass without deterioration. For such reasons as these some foundrymen are putting off the day when they shall begin to bother with pyrometers, while others

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[1] Assistant Physicist, Bureau of Standards.
[2] Physicist, Bureau of Standards.

have passed the experimental stage and no longer consider the pyrometer too troublesome to handle.

There is need, not so much for improvements in pyrometers, as for wider experience with the performance of pyrometers and greater familiarity with the underlying theory. In a survey of twenty-four representative foundries, undertaken to obtain a wide view of present practice, the authors, whose experience has been, for the most part, in pyrometry found that most of the troubles

FIG. 1

encountered in the use of pyrometers for pouring temperatures result from unfamiliarity with the theory of their action. This lack of familiarity exists not only among foundrymen but also among the representatives of a few pyrometer manufacturers who consequently do not give proper instructions to the users of their instruments. In order, then, that the pyrometry of molten brass be promoted, it is considered proper to include in this report a brief outline of the essential principles of thermoelectric pyrometry.

The Thermoelectric Pyrometer

The simplest thermoelectric circuit consists of two dissimilar wires, for example, chromel and alumel joined together as shown in Fig. 1. If the junction at A is at a higher temperature than that at B, an electric current will flow in the direction indicated by the arrow. If the wires are homogeneous, that is, of uniform composition throughout their length, it may be considered for practical purposes that the current is caused to flow by two emfs, one at A and one at B,[3] which generally oppose each other so that the net emf is their difference.

If the junction B is maintained at a constant temperature of reference then the emf in the circuit will be a measure of the

[3] A consideration of the Thomson emf is not essential to this description.

temperature of A. In order to measure the emf, the circuit is opened at B and a millivoltmeter connected through extension leads as shown in Fig. 2. Extension leads for a base metal couple are usually made of metals similar to the two elements of the couple so that no emfs arise where they are joined.[4] In Fig. 2 the junction B of Fig. 1 is replaced by two junctions, the "cold junctions" at the terminals of the instrument. There are now two emfs, one at each terminal, whose algebraic sum is equal to

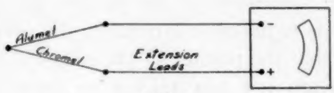

FIG. 2

the emf at B in Fig. 1 for the same cold junction temperature. That is, the inclusion of the leads and meter does not alter the total emf provided temperatures of the hot and cold junctions are the same as before. Likewise the thermocouple can be opened at A as in a fork type couple for immersion in molten brass. Again, the emfs will not be altered, provided the immersed portions of the two wires are at the same temperature as in the previous case.[5] The emf of a bare thermocouple in molten brass depends upon the temperature of the wires at the surface and not primarily upon the temperature of the brass. The brass may be at a different temperature, acting only as an electrical connection.

Suppose the ends of the open or fork-type couple are suddenly immersed to a depth of three inches in molten brass. The emf of the couple increases as the temperature of the three inches of wire rises and will reach a value corresponding to the temperature somewhat below that of the metal. The temperature of the wires at the surface is lower than that of the metal or wires two or three inches below the surface, due to the heat losses

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[4] Leads and couples are often slightly different and for this reason the junctions between them should be kept relatively cool.

Copper leads should not be used in the equipment described in this paper for use in brass foundries. In such cases the cold junctions are in the handle of the thermocouple mounting and the cold junction temperatures will vary widely.

[5] The absence of galvanic emfs is here assumed. Experiment indicates that these are either absent or small.

from the surface of the brass and to heat conduction along the wires. The emfs set up in the immersed three inches are short circuited by the brass. If now, as soon as the ends of the couple have reached the temperature of the metal three inches below the surface, the couple is withdrawn until the ends are just immersed, the emf corresponds to the temperature of the ends which are momentarily at a temperature which is practically the same as that of the metal two or three inches below the surface. Of course, the tips will cool rapidly and the couple must be withdrawn as rapidly as the movement of the pointer of the indicator will permit. Practice is required in estimating the proper rate of withdrawal, in order that the pointer of the meter will rise to a maximum and fall again not too quickly to prevent the maximum reading being observed. The same procedure is followed when the tips of the wires are welded together, because in this case, also, the immersed portion of the couple is "short circuited" and the emf corresponds to the temperatures of the wires near the surface.

Stirring the metal will bring the reading nearer to its proper value by reducing the temperature differences in the brass but does not eliminate the effects of conduction along the wires. The practice of both stirring the metal and withdrawing the couple will give the most nearly correct indication of the temperature of the brass.

In the simple thermoelectric circuit shown in Fig. 2, the deflection of the indicator needle or pointer is proportional to the current flowing through the indicator. That is the indicator is, in truth, a microammeter whose scale is graduated in degrees. The current in this circuit will be according to Ohm's law, equal to $\frac{E}{R}$ where E is the net emf generated and R is the total resistance of meter, leads, and couple. If the deflection of the pointer is to depend only upon E, then R must remain constant. For this reason good millivolt meters are made with a high resistance (300 ohms or more) most of which is in manganin whose resistance is practically unaffected by changes in the room temperature, that is to say, it has a low temperature coefficient of resistance. Suppose that, with a 300 ohm meter the resistance of the leads

or couple changes by 1 ohm. This change corresponds to approximately 1/300 of the indicated temperature, for example, 7° at 2100°. Variations of many ohms are frequently met with when the oxidized and corroded tips of a bare fork type couple are connected by molten brass. Suppose that an instrument having a resistance of only 5 ohms is used. In this case a change of 1 ohm in the external circuit corresponds to an error of 20 per cent or over 400° at 2100°. For this reason the users of these low resistance meters must exercise extreme care in keeping the external resistance constant. Moreover, low resistance meters usually have a higher temperature coefficient of resistance than do high resistance meters because the ratio of copper to manganin in the low resistance meter is higher than the same ratio in the high resistance meter. When such a low resistance instrument is used with a fork-type or open-end couple for molten brass large errors must necessarily result from very small changes in the resistance across the ends of the couple as well as small changes in the internal resistance of the meter due to changes in the room temperature. It may be argued by the maker of such an instrument that low resistance compels the user to clean the ends of the couple. However, it is only by keeping the ends clean that correct readings are obtained even with the instrument having a higher resistance.

The large variations in the resistance between the tips of a bare fork-type couple are caused by the formation of oxide films on the surfaces of the wires. These oxide films are always formed when bare couples are used in molten brass. When the fork-type couple is immersed in brass, the current passes through the oxide films and the brass and as the resistance of these films increases, the current and consequently the reading of the indicator decrease even though the temperature and composition of the tips remain constant. In the case of a new fork-type couple the resistance between the tips is very low and if the ends of the tips are welded together another path of very low and comparatively constant resistance is provided. In this case the resistance of that part of the circuit which is in the molten brass is always very small and variations in this low resistance do not appreciably affect the

total resistance of the circuit. Thus it is seen that the resistance of the circuit is steadied by welding the tips and in addition the necessity of cleaning them is not as great. Usually the welded tips are satisfactorily cleaned if the collected metal and slag are removed by dragging the tips across the surface of the pot when they are withdrawn after taking a reading.

In the use of a portable pyrometer particular attention must be given the cold junction temperatures. Some indicators are equipped with automatic cold junction compensating devices. In any case, the pointer of the indicator should be set by means of the "zero adjusting" screw to the cold junction temperature while the circuit is open. If copper leads are used the cold junctions are located at the points where the copper is joined to the chromel-alumel elements, while if extension leads are used the cold junctions are located at the indicator. Any error in obtaining the cold junction temperature will produce an error of the same magnitude in the pouring temperature. The portable indicators not having automatic cold junction compensation should be equipped with thermometers mounted in or upon the cases for convenience in applying corrections. Indicators having automatic cold junction compensators should be set at the time of installation, compensation being designed to take care of variations in the cold junction temperature. The operation of this compensator should be checked frequently by means of a thermometer.

The vital part of the thermoelectric circuit under consideration is that at the bare tips connected by molten brass or by a weld which is immersed. Suppose a new couple of the fork-type is suddenly immersed three inches through a clean surface as mentioned before, and held steady. The wires just above the surface will soon reach a temperature very near that of the upper layers of the brass. At this time the pyrometer will indicate a temperature slightly below that of the surface. If the couple has been used until the wires are badly contaminated, the indicated temperature will be even lower. Neither welding the tips of the couple nor partially withdrawing them will eliminate the error due to contamination. For this reason the wires must be kept clean and unalloyed. Protecting the tip of the couple as done by

Mr. Grubb and described elsewhere[6] in this symposium avoids this error completely except when the wires near the tip of the protecting sheath deteriorate. Using clean couples with proper precaution, experience and practice have shown that it is possible to obtain readings agreeing with each other to better than 10° Fahr., which is probably less than the temperature differences existing in the brass.

The checking or calibration of pyrometers will not be described here in detail. The methods have been described many times, and treatments of the subject are conveniently at hand in Liddell's Handbook of Non-ferrous Metallurgy and in Technologic Paper No. 170 of the Bureau of Standards. Unless the checking is carried out by the simple expedient of comparing one instrument with another, the operator or user should refer to treatises on pyrometry.

Pyrometers used in molten brass should be checked very frequently, in most cases once a day is not too often. Some pyrometer manufacturers can furnish instruments and thermocouples which will check to 5° Fahr. consistently, but experience is required for one in the foundry to be able to obtain an accuracy of 5° Fahr. either with one instrument or in a comparison of two.

Present Practice and Equipment

Most of the pyrometers found in the foundries visited are fairly well suited to their purpose, and apparently each of the various equipments on the market was giving satisfactory results in some one or more of the twenty-four foundries visited. These are made in whole or in part by nine manufacturers of pyrometric instruments. Thus it is apparent that the equipment available will give satisfactory service if properly used.

In many cases it was observed that the equipment was being improperly used. For example, some foundrymen were not setting the pointer of the indicator or meter for correct cold junction compensation. In some cases the instructions of the pyrometer manufacturers were inadequate and incorrect. In other cases the bare couples were not kept sufficiently clean.

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[6] Grubb, A. A., Marshall, L. H., and Nass, C. V., *A Thermo-Couple for Ladle Temperatures of Brass,* Trans. A. F. A., vol. 34, pp. 663-668, 1927.

The survey led to the conclusion that when the couples are used bare, heavy wires with welded junctions give the most satisfactory service. Such couples are sturdy, give steadier and hence quicker readings, with the result that more readings can be obtained with each set of tips.

There is, however, no decided advantage in the welded tips when the wires of the open type are kept clean. When the user of a welded couple finds that the tip has corroded through he has a choice of cutting the end off or replacing the couple with a new welded one. The choice depends somewhat on the damping characteristics of the indicator, that is, whether the pointer comes quickly to rest without undue oscillation. The best indicators are not overdamped nor seriously underdamped. Slight underdamping is desirable because a shorter time is required in getting a reading. If the pointer swings too freely with considerable underdamping when a fork type couple is used it can be made steadier by using a welded tip which has a steadier resistance.

Not enough of the foundries visited were keeping records of the performance of their thermocouples to enable a conclusion to be drawn concerning the relative life and cost of the open and welded couples.

The data from the records obtained indicate that open couples give 25 per cent fewer readings than welded ones. But if the guesses from other foundries were averaged in, the result would indicate that open couples give 15 per cent more readings. The cost of welding couples is an item offset by the greater number and quicker readings which can be obtained with welded tips. The relative cost will depend upon the composition of the brasses and bronzes, on the type of welding equipment used and on various personal factors such as the skill of the melter and of the man using the thermocouples. In any case the cost of thermocouple wire should be less than two cents per reading. Sufficient tips are usually welded to serve the foundry for a day or more. After these tips burn through they are replaced by others and the old tips laid aside to be rewelded at any convenient time. All of the corroded wire must be cut away before rewelding.

According to data at hand the welded tips gave on the average 25 readings before corroding through. Only the open type

of couple is being used to any extent in high phosphor bronze. It is not yet proved that this is better than welding.

As to the type of indicator giving the best results the findings were in favor of the high resistance meter of 300 ohms or more used with extension and not copper leads. High resistance meters are being made with sufficient ruggedness to withstand a great deal of transporting about the foundry. However, the most progressive foundries have established pyrometer stations where the indicator is mounted permanently and where every ladle of brass is halted for one minute or so while the temperature is measured and the metal is allowed to cool to a point where it is first possible to pour a good casting. This system is described by other contributors to the symposium. We believe that this system is far superior to the practice of carrying the pyrometer about the foundry.

The following brief table summarizes the pyrometer equipment and practice employed in the foundries visited:

11 foundries are using bare fork-type chromel-alumel wire of heavy gage.

Of these

5 use low resistance meters

6 use high resistance meters.

7 were using bare welded chromel-alumel couples of heavy gage.

Of these

3 use low resistance meters

4 use high resistance meters.

4 foundries use bare twisted nickel-nichrome couples of small gage. All of these use high resistance meters, necessarily.

2 foundries use the special protected couple devised and described in this symposium by Mr. Grubb of the Ohio Brass Company.

Both use high resistance meters.

1 foundry is using rare metal couples protected by special tubes, with potentiometer indicators.

1 foundry is using an optical pyrometer frequently.

3 foundries are not using any pyrometric equipment at present. Each has purchased a pyrometer in the past.

Summarizing the data as to type of indicators:

16 use high resistance meters
8 use low resistance meters
1 uses a potentiometer indicator
1 uses an optical pyrometer
3 use no pyrometers.

Summarizing according to the method of use:

6 measure temperatures of all metal poured
3 measure temperatures of "practically all" the metal poured
8 used their equipment on special alloys or castings *or when in trouble*
4 use their equipment "frequently"
3 were not using their equipment.

Of those using bare couples either open, twisted or welded:

3 withdraw the couple to the end before taking a reading
8 stir the metal and read
8 hold the couple steady and immersed about 3 inches
1 record is not available, on account of intermittent use of equipment.

It will be noted that in the above summary only three out of twenty carry out the process of immersion and partial withdrawal as described in previous paragraphs. The eight who stirred the metal with the couple were obtaining results nearly as satisfactory, but all would obtain more consistent results if they followed the example of the first three.

It was learned a few years ago that alumel wire dissolves more readily in most brasses than does chromel. For this reason the manufacturers are now furnishing, in the heavy gage couples, No. 2 or 4 gage alumel with No. 6 or 8 gage chromel.

In some foundries the practice is to measure temperatures not only in the ladle but also just after melting in the furnace. This is not always essential with electric furnaces. Expert furnace control with measurements of temperatures of metal in the ladle is considered generally satisfactory. The thermocouples are used in the same manner in the measurement of melting temperatures as in the measurement of pouring temperatures. The welded couples give the best results in the furnace.

Accuracy Now Obtained in Foundries

From close observations of the equipment found and the manner in which it was used we believe that in some cases temperatures are being measured with an accuracy of about 15° Fahr. In such instances the measurements were consistent to about 10° Fahr. or even better. Such accuracy is obtained where it is the practice to check the pyrometer daily and carefully clean the couples after each reading.

We estimate that in some foundries the errors are usually 100° to 150° Fahr. and the consistency of measurements not better than 20° to 40° Fahr., although this does not agree with the estimates of the users. This low accuracy is being obtained with low resistance meters, copper leads, uncleaned couples and no checking at all. These foundries had no laboratory in which the instruments could be calibrated.

Indirect Control of Pouring Temperatures

In two of the foundries visited pyrometers were not in use partly for the reason that there was satisfaction in the results obtained by careful control of the electric furnaces used for melting. One of these two is using arc type furnaces and the other induction furnaces. These foundries are pouring all metal into chilled ingot molds. In both cases the furnaces are controlled by noting the weight of the charge and regulating the power and kilowatt hour input accordingly. In using the induction furnaces for melting brasses an indication of the temperature attained is given in the vaporizing of zinc in the secondary circuit and the consequent unsteadiness or kicking of the ammeter when the brass in the secondary circuit reaches a certain temperature.

Recommended Equipment and Practice

Indicators:—High resistance millivoltmeters with scales graduated in temperature, designed for wall mounting, protected from dust, and not subject to large errors from changes in "room temperature," should be used. Cold junction temperatures should be compensated, (1) automatically, (2) by burying the cold junctions in the ground, (3) by thermostating, or (4) by ready adjustment or correction. If the pointer is to be adjusted for cold junction temperatures, instructions should be printed on the meter. The moving coil of the meter should be critically damped or preferably slightly underdamped, when the thermocouple circuit is closed.

Extension Leads:—Leads, or connecting wires, between meter and couple should be made of alloys similar in composition to the couple so that their emf-temperature relation between 0 and 200° Fahr. is nearly identical with that of the couple. They should not be made of copper wire. Insulation should be heavy, moisture proof and the leads should be strong enough not to develop broken strands until after long use. The ends of the leads should be soldered to metal terminals plainly stamped + and —. Color of insulation should not be used as the only means for identifying the polarity.

The resistance of the leads and couple should equal the figure marked on the meter.

Thermocouples:—Present practice favors the use of the chromel alumel combination of wires for thermocouples, although an alloy more resistant than alumel to solution in brass is highly desirable. In this connection it may be said that it should be possible without more than a very little experimenting to find an alloy of nickel and chromium or of iron and chromium which would give 10 or more microvolts per degree against chromel P and be nearly as resistant as chromel to corrosion by brass. Such an alloy in combination with chromel P, giving a relatively low emf as a thermocouple would require that the indicator be of the type now used only for rare-metal thermocouples. Some of the pyrometer manufacturers can supply high resistance meters for these lower emfs (about 15 millivolts for full scale deflection) which are very rugged and suitable for use as mounted instruments.

Practice also favors the use of No. 2 to 4 gage alumel with No. 6 to 8 chromel wire cut in short length for replaceable tips in a portable cane or stick. For general practice where there is little or no previous experience the welded couples are recommended rather than the fork-type of couple, because they give steadier readings with less chance of misinterpretation when the couple is being withdrawn from the molten brass. As an alternative the arrangement of Mr. Grubb described elsewhere in this symposium can be recommended for those who are ready to make their own parts according to Mr. Grubb's directions.

It is preferable to use regular thermocouple wire in the cane itself to connect the replaceable tips with the extension leads. The tips should be supported by heavy short terminals not exposed to direct radiation from the hot metal, if high accuracy is desired.

Purchases and Installation

Coils of thermocouple wire can be purchased by the pound, with a guaranteed accuracy of 10° Fahr. It can be more economically purchased in lots of not less than fifty pounds if the purchaser is convinced that pyrometry of molten brass is practical. This wire can be cut into lengths of fifteen to twenty-four inches and couples welded either with an arc or oxy-acetylene torch.

Fluorspar or borax glass is used as a flux. The welded joints should contain as much of the chromel alloy as possible and be solid and free from oxide or gas holes. They need not be limited in size.

Two or more canes or sticks with the necessary extension leads should be provided.

A high resistance wall type indicator, dust proof or in a dust-proof case, and a portable checking indicator or portable potentiometer is the minimum number of instruments for satisfactory results. It is often advisable to install a multiplepole dust proof switch close to the indicator to enable the operator to quickly change from one couple to another.

A pyrometer station is arranged, consisting briefly of mounted indicators and switch, two or more thermocouples attached to the switch and hung in racks, a shelf or small bench with a wire brush; coarse file and heavy wire cutters for care of thermo-

couple tips, receptacle for spare tips, shelf for record sheets, and a clock. (Recording pyrometers now on the market are not adaptable for recording pouring temperatures of brasses and bronzes). Places for deoxidizers, cooling bars, skimming rods and other foundry equipment are provided.

The station is placed for convenient routing of ladles so that the ladles may be set down in easy reach without exposing the meter to hot drafts or excessive radiation.

Procedure in Pyrometric Measurements

The procedure to be followed in making the measurements will be only briefly described because tried methods are described in other papers of the symposium. The hot metal is brought to the pyrometer station, the surface is skimmed, and a couple is immersed three to four inches. After stirring about slightly for a few seconds the tip is withdrawn until the depth of immersion is one inch or less and the maximum reading of the indicator noted. If the temperature is too high cooling bars are added or a time allowed for cooling. The exact cooling rate of a quiet ladle should be known. This will depend upon the composition of the brass, on the temperature and on the nature and preheat of the ladle. The couple should be withdrawn immediately after a reading is obtained. If the temperature is too high the metal should be allowed to cool and another reading taken after a suitable length of time. A tolerance can be established according to the needs of the foundry. The actual final reading should be recorded together with the necessary identifying information. The procedure from this point may vary widely and may properly be developed in each foundry.

In smaller foundries most of the work at a pyrometer station can be handled by the foreman, but in larger foundries it is well to give the job to a student employee under the tutorship of the superintendent or metallurgist. In any case the individual using the pyrometer should learn something about principles of pyrometry. All the papers of this symposium should be perused studiously and kept for reference. In addition the study of general treatises on pyrometry is advisable. Reference has been made to two of these easily obtainable at present.

In the beginning of the employment of pyrometers in any foundry records should be kept of the life and performance of the pyrometric equipment and of the improvement of product that may result.

Conclusion

The progress of pyrometry in foundry practice will depend almost wholly upon the progressive spirit of the foundrymen. It will depend of course upon improvements in pyrometers but radical improvements of this kind should not be expected. It will depend also upon the accumulation of "temperature data" and their correlation with composition of alloys, type of casting, and foundry practice. These data will accumulate rapidly and should be made available to the whole industry. Errors will creep in and allowances must be made. An accuracy of 10° Fahr. at 2000° Fahr. is considered attainable today. An accuracy of 40° Fahr. would give results superior to those obtained in many foundries at the present time.

An effort has been made in this paper to record some of the practices in pyrometry and to bring out some of the details which would not otherwise be brought to the attention of foundrymen.

Some of the descriptive matter presented is in the nature of specifications. A conservative attitude has been taken not only because the authors are somewhat unfamiliar with non-ferrous foundry practice, but because it is believed that such specifications should be drawn at a later date by a co-operative committee of foundrymen and pyrometer manufacturers. A selected group of foundry managers should be urged to collect data with the above purpose in mind.

Testing Cast Iron*

By Auguste-Eugene Le Thomas,† Indret, France

The testing of cast iron is now regarded by iron founders the world over as a question of the greatest importance. The technical congresses which have been held for some years past have afforded opportunities for investigations and the exchange of views in regard to the subject. At the Liege Congress, organized by the Technical Foundry Associations of France and Belgium in October, 1925, a number of reports on the subject were presented, and were discussed in the presence of large audiences.

The first of these reports, written by J. W. Bolton on behalf of the American Foundrymen's Association, as an exchange paper for the Belgian Association, gives an account of the results of numerous experiments and arrives at conclusions which are worthy of special examination. A second report, the author of which is Joaquin Ferrer, manager of the foundry and laboratory services of the Maquinista y Fundiciones del Ebro company of Saragossa, bears witness to the utility, economy, and precision of Frémont's tests. A third report, signed by Captain Planas, of the Precision Workshops of the Technical Service of the Spanish Army, has aroused particular interest. The author, after having considered all the methods of testing cast iron hitherto proposed and after dealing with them in minute detail (the report consists of two bulky volumes) has succeeded in making a rational choice of methods which render it possible to characterize all kinds of cast iron, and to establish experimental rules by means of which tests carried out in different laboratories can be compared. The author of the present paper himself submitted for the examination of the congress an essay on the same subject, several points of which will again be referred to below.

These reports, and others of even greater interest, which have been presented at other congresses, or have appeared in the numerous reviews written in all languages, all point out a com-

*Exchange paper presented on behalf of The Foundry Technical Association of France.

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mon object, namely: the discovery of an efficient method of correctly ascertaining the strength of iron castings, and, incidentally, of investigating the possibility of obtaining a more exact knowledge of the material itself, and developing its useful qualities.

It may be objected that certain of the conclusions arrived at are based exclusively on *a priori* theories or on laboratory tests. The efficiency of such methods of testing will not be definitely proved until the industrial application is shown in practice to be in conformity with the ideas of the scientific investigator in his laboratory. "An ounce of practice is worth a pound of theory." The aim of the present work is confined to developing the observations made in the course of several years and in some of the larger foundries regarding the application of those methods which have been retained today by the Association Technique de Fonderie de France.

Economic Justification of Tests

In the first place, and in order to throw some light on the question, we will make a few remarks by way of parenthesis. Does the foundryman derive any advantage from making tests? We know, of course, that he is bound to carry out certain tests in order to fulfil the conditions stipulated in the purchaser's specifications, but are these tests of any interest to him beyond that of complying with his obligations?

In our opinion, such tests enable him to appreciate the actual value of the method of manufacture and thus afford him considerable assistance. As H. le Chatelier has pointed out,[1] "One of the most valuable services rendered by the different methods of measuring is the reduction and even the elimination of rejections."

The same author also makes the following observation:[2]

"In the every-day routine of a works the object it is sought to obtain from all methods of measurement employed as an aid to manufacture—chemical analysis, microscopic metallography, etc.—is to decrease rejections by insuring the uniformity of the

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[1] Science et Industrie, Flammarion, 1926.
[2] Revue de Metallurgie, 1910, p. 504.

elementary factors upon which the quality of the manufactured product depends. This reduction of waste is the chief preoccupation in all industrial operations, for in the majority of cases a profit is either shown or not shown in accordance with the percentage of such waste. In order to obtain a reduction of this percentage, it is necessary, after having ascertained that any manufactured product is unsound and unfit for use, to discover the particular stage of manufacture which has been defective."

H. le Chatelier further remarks[3] that: "Modern testing practice could still be considerably developed. Small works often make no tests whatever, and large works too often content themselves with carrying out reception and inspection tests, while neglecting to make unceasing efforts to regulate the most important processes of manufacture. Too much reliance is placed on the hands and eye of the workman.

"And nevertheless the scientific control of manufactures renders it possible to effect considerable economy by reducing and, sometimes, even eliminating rejections."

The primary, but not the sole, object of the tests carried out in the works is to recognize, if possible, the defects in manufacture and to correct them.

It would indeed be a mistake to suppose that an apparently faultless system of manufacture has no need of inspection. When one has read a striking passage in literature, one marks it in order to be able to find the place again easily, without having to run through the book should one wish to re-read it and draw some other lesson from it. In the same way, when a successful period occurs in manufacture, it is necessary to analyze its elements with greater care than ever. Nothing is eternal, as iron founders, unfortunately, perhaps know better than many people, and it would be disappointing, owing to a change in the nature of the supplies or in the tools, to have again to make the tests or experiments which had led to the former degree of perfection now lost.

Tests will therefore continue to be made, either by force of circumstances or voluntarily. We are among the number of those who always do so voluntarily, after the manner of a good chef, who is anxious to serve up dishes cooked to a nicety, a task for

[3] Science et Industrie.

which it is necessary not only to know how to prepare a sauce, but also how to taste it.

Tests are made with the object of obtaining as exact an idea as possible of the qualities of the product under service conditions.

An ideal method of testing would be one which classified the material in a certain order of merit, this order being the same as that indicated by observations made of the behaviour of the material in actual use.

Confining ourselves to mechanical resistance, as we are only concerned here with so-called machine cast iron (for castings used in machinery and engineering), it is natural that in the forefront of the methods recommended we should find those which indicate a physical property of the material, such as its shearing or bending strength. This, however, is not indispensable, and we shall show that other properties, as, for example, the state of the metal in respect of carbon and its distribution, ascertained either chemically or micrographically, enable us to classify the material in the same manner as that referred to above. It may be said that any property which can thus be used in order correctly to classify the tested products is a "criterion of quality," or, more shortly, a "standard."

It is, however, clear that a mechanical test, micrographic examination or chemical analysis, even though they are supposed to possess the same virtues, from the point of view of the classification of cast iron for machinery in order of quality, cannot be equally satisfactory in practice, and this induces us to say a few words as to the characteristics which testing methods ought to possess.

Necessary Characteristics of Industrial Methods of Testing

There are many methods of testing, but not all of them are suitable. As we have pointed out above, a method of testing, in order to be of practical value, must primarily utilize a property of the material which will permit its behaviour in use to be estimated, must, in short, afford a "standard"; moreover, in order to be specifically industrial, it must possess several other characteristics, such as precision, uniformity, rapidity, and cheapness.

Methods must be precise, from which it follows more particularly that the results they give should be measured. If precision is lacking, errors of personal judgment may seriously affect the results. This is equivalent to saying that the order of magnitude of accidental errors necessarily made in the course of measuring should be small relatively to the order of magnitude of the result. In other words, the probable error should be small, or, to put the matter in yet another way, the measurement should result in a number—the result of the test—of which at least the two first indicative figures should be exact.

Methods must be uniform, that is to say, unforeseen or unexpected circumstances, such as a change of operator or testing machine, or any other alteration—even presumably of slight importance—in the condition under which the test is carried out, should in no way affect the value of the result. For example, it has been shown that the methods of applying tensile tests to cast iron are not uniform, industrially speaking, because the tensile testing machines usually found in works laboratories make it difficult to avoid several hidden causes of error which often affect the results of the tests and render them irregular.

Methods must be rapid, so that the classification of the material tested can be made as soon as possible after the test piece has been cut, and, in particular, before the machining of the product is begun, so as to avoid unnecessary labor costs should the material be rejected.

Finally, methods must be economical, so that the cost price of the product is only slightly affected by the tests made.

We shall show that the methods of testing cast iron which we have retained, and which we constantly employ in common with other companies and works, possess in the highest degree the above qualities of precision, uniformity, rapidity, and economy.

As, however, the aim of the present report is to discuss objective experiments rather than to develop theories, we will explain in a few words why we were led to interest ourselves in the methods of testing cast iron, and to make a selection among those submitted to us for examination. As will be seen, our chief objective was to obtain economy of manufacture.

Reasons Governing the Choice of Methods of Testing

The author holds an appointment, in the capacity of engineer in charge of the laboratory and metallurgical department, at the Indret Works of the French Navy. These works, under the thoroughly scientific management of the chief engineer, M. Moutard, a great friend of progress, constitute an experimental department which tests or invents improved apparatus in connection with the driving machinery of battleships, and also include an arsenal in which are built turbines, boilers and engines of all kinds. These machines have always enjoyed a high reputation in the world of marine boiler and engine makers.

This reputation—if we may use the term—is the result of a necessity. Battleships are provided with very powerful engines (the cruisers now under construction, of ten thousand tons displacement, have engines of more than 130,000 HP) and great efforts have to be made in order to obtain units at once powerful and light, as it is obvious that any saving in the weight of the engines is in favor of the fighting value of the ship—artillery, ammunition, and fuel, etc. On the other hand, the component parts of these apparatus must necessarily be free from defects, as sometimes in war, as in peacetime, the slightest accident may have tragic consequences. The materials used in construction must, therefore, necessarily be exceedingly strong, and, in particular, the foundry products must be of the highest quality.

This necessity, which is binding upon all constructors of battleship engines, and, to a lesser extent, upon builders of mercantile marine installations, had led, before the war and as far as foundry-work is concerned, to the employment of raw material of first-class quality. From the point of view of the manufacture of machinery cast iron, a large proportion of exceptionally pure products was used, these being always identical and enabling pieces of the required high quality to be produced, an important factor, as already pointed out, in the fighting value of vessels of war.

Though the economic conditions prevailing before the war rendered it possible to employ such raw materials without incurring undue expense, a great change took place in the post-war period. Special grades of cast iron reached very high prices, and certain brands even disappeared from the market. At the insti-

gation of the director of the works, the writer made certain investigations with a view to discovering whether it were possible to replace the excellent but expensive formulæ until then employed on the manufacture of machine cast iron by other processes which, although perhaps of a more complex nature, would prove less costly.

In attempting this evolution in the methods of manufacture, it was necessary to proceed on firm ground. At no moment was it permissible to risk failing to satisfy the condition as to first-class quality imposed on our machinery cast iron. It was also necessary to avoid any stoppage in manufacture which might entail a delay in deliveries. In order to comply with these requirements, it seemed to us above all indispensable to adopt absolutely sure methods of testing which would enable us at any moment to estimate, without any possible chance of error, the degree of quality of the cast iron products, and be capable, if any variations in the regularity of manufacture took place, of placing these in evidence and diagnosing the causes.

The tests until then carried out at our works consisted in testing bars cast separately. We know, of course, that these tests have a certain value. If the mold of a piece has been prepared in conformity with the rules of the art of molding and in accordance with the plans, and if, moreover, the iron cast in the mold is intrinsically good (which can be ascertained by testing a bar cast separately) it may be inferred from this combination of favorable circumstances that the casting has every chance of being satisfactory. It will, however, be granted that this result is only probable, and not certain.

Now, for our purpose, it was necessary not only radically to alter the composition of the burdens, but also, and above all, to deliver castings thoroughly sound and stronger than ever, intended for the engines of vessels of exceptionally high power, such as those which have been built by the different Powers who took part in the Washington Conference.

The methods of testing which, after a thorough and critical examination and a number of searching experiments, seem to us the most likely to prevent variations in manufacture and ensure the perfect quality of the castings themselves, are those invented

by M. Frémont and M. Portevin. We shall describe these methods later, after examining the properties of high resistance cast iron as they appear from the investigation of the eminent scientist, M. Portevin.

Properties of High Resistance Cast Iron

As is well known, common iron-carbon alloys exist in two distinct forms. The first, which from the physico-chemical point of view is the stable form, is the ferro-graphite system. At the ordinary temperature the iron is separated from the carbon. Metallographists are then able to recognize in a polished section, examined under the microscope, the presence of two constituents, which they call "ferrite," which is of the nature of iron, and "graphite," which is a form of carbon. The ferro-graphite system can be observed separately in malleable cast iron.

The other form in which iron-carbon alloys occur is the "ferro-cementite" system, which is metastable. At the normal temperature the carbon is combined with the iron in the form of carbide of iron known as Fe_3C, or cementite. The excess iron is free from carbon. Further, the carbide of iron and iron are sometimes combined in an eutectic mixture called pearlite, the result of transformations in the interior of the solid on cooling, and composed of seven parts of ferrite to one of cementite.

The two systems of equilibrium of iron-carbon alloys co-exist as a rule in cast iron, so that the following constituents may be observed: Graphite, free ferrite, free cementite, and pearlite.

(1) From the micrographic point of view the typical structure of sound cast iron may be defined as follows:[4]

Pearlite, finely laminated (i. e., the laminæ should only be observable when magnified two hundred times or more); graphite in loose and well distributed elements; a very small quantity of cementite, which had better be absent altogether than present in excess; absence of ferrite.

We give, further on, micrographic examples of such forms

[4] A. Portevin, "Revue de Metallurgie," 1922, p. 227, "Micro-Structure de Fontes Aciérées."

of cast iron, as well as indications as to the most suitable method of examination (see Figs. 8 and 10).

The structural characteristics which denote a decrease in the physical properties of cast iron are:

The presence of ferrite; a large quantity of graphite, or graphite in thick laminæ; pearlite of coarse structure; too great a proportion of cementite.

In the lot of cast iron dealt with we were easily able to recognise the accuracy and precision of this standard. Moreover, as we shall see later on, micrography has been a most valuable guide to us in manufacture.

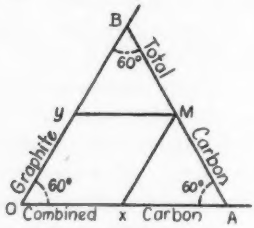


FIG. 1

(2) From the chemical standpoint, M. Portevin has pointed out the advantages to be derived from using a diagram which shows the contents of combined carbon and graphite (or total carbon), and from which may be deduced the probable crystallographic state. We have just had occasion to note the importance of the contents of graphite, on the one hand, and of combined carbon (cementite and pearlite), on the other. Starting from the obvious equation:

Total carbon = combined carbon plus graphite, we will mark off on the two sides of an angle of 60 degrees (Fig. 1)

Ox = percentage of combined carbon.

Oy = percentage of combined graphite.

These two oblique co-ordinates define a point M. If we draw

through M a straight line inclined 60 degrees to both axes it is clear that

$$A\,B = Ox + Oy,$$

an equation which, on being compared with the foregoing, signifies that A B represents on the same scale as above the content of total carbon in the cast iron. We may say, therefore, by means of these symbols, that M is the point which represents the state of the cast iron in regard to carbon and of the distribution of this element. In particular, the points of the axis O A correspond to steels and white irons (unstable equilibrium) and the axis O B contains the points representing cast iron cooled so slowly that the

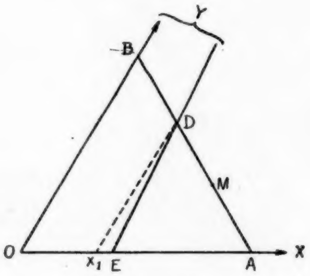


FIG. 2

carbon is entirely separated in the state of graphite (stable-malleable equilibrium).

Now among the different forms of cast iron of which the total carbon content is A B (Fig 2) there is one represented by the point D, of which the content Ox of combined carbon is just sufficient to saturate the iron in the state of pearlite. In other words, this metal contains neither free ferrite nor free cementite, the ferrite and cementite being present in such proportions that they readily combine in the form of pearlite, namely, one part of cementite to seven parts of ferrite.

This iron, therefore, only contains pearlite and graphite.

It can easily be shown, by means of arithmetical calculation, that the position of the points D when the total carbon content

A B varies, are along a straight line joining the point E determined by O E = 0.85 per cent, and which is the figurative point of fine pearlite to the apex Y of the equilateral triangle and OX = OY = 100 (Fig. 2).

It can also easily be shown that the points situated on the right of E Y represent metals containing the three constituents:

Graphite + cementite + pearlite,

whereas those on the left represent cast iron composed of:

Graphite + ferrite + pearlite.

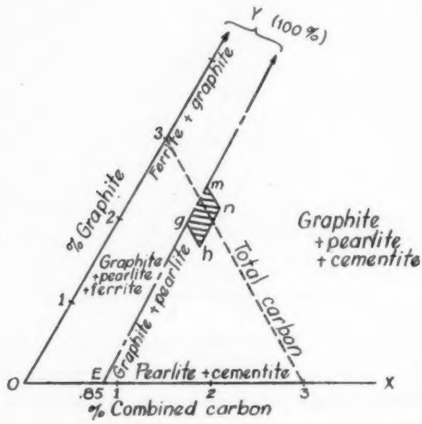


FIG. 3

Cast irons containing graphite, pearlite, and a very little cementite have their figurative points almost at the contact of EY, on the right. If their mechanical quality is to be good, it is in practice indispensable that their content of total carbon should be about 3 per cent. A larger percentage, in fact, multiplies the graphite laminæ, a circumstance which, as we have seen, is unfavorable. On the other hand, cast iron containing less carbon is less fluid and harder to cast. The figurative points of cast iron of good quality should, therefore, be assembled in a small area such as m, n, g, h (Fig. 3).

We have verified this fact in a lot of machine castings constituting a miscellaneous collection of machine parts (Diesel marine engines of various makes and also of German origin). For this purpose we classified the irons as follows:

(1) Those with a shearing strength of over 23 kilos per sq. millimeter (32,713 pounds per sq. in.), and which are designated in the graph by a cross.
(2) Those with a shearing strength of between 19 and 23 kilos per sq. millimeter (27,024 to 32,713 pounds per sq. in.), and which are denoted by a small circle.
(3) Iron with a shearing strength of less than 19 kilos (27,024 pounds), and which are indicated by a dot.

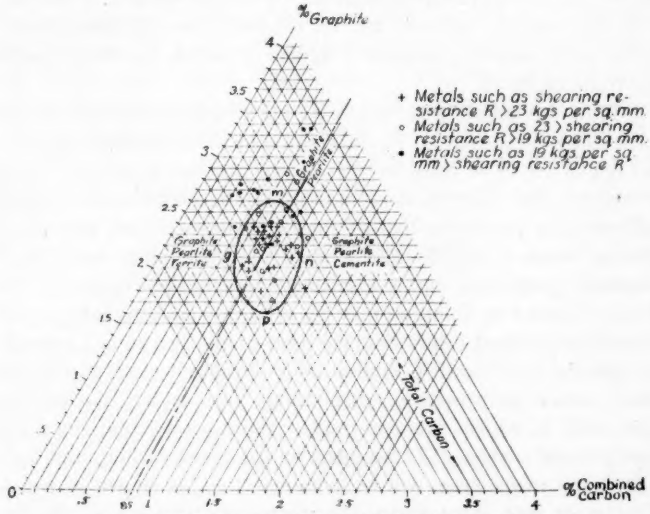


FIG. 4—CAST IRONS, PLOTTED ACCORDING TO QUALITY (PORTEVIN'S DIAGRAM)

We then marked on Portevin's triangular diagram the figurative points of the castings tested, distinguishing them in accordance with the qualities defined above. The graph thus obtained is reproduced in Fig. 4 and, upon examining it, one cannot help being struck by the confirmation afforded by these statistics of the foregoing theory. As can be seen, the cast irons of very good quality

are assembled round about the point defined by the co-ordinates:

Total carbon = 3 per cent.

Combined carbon = 0.80 per cent.,

while, inversely, the mediocre metals have their figurative points distant from the same center. Conversely, after having made the analysis, it may be said that a metal the figurative point of which marked on the triangular diagram is noticeably distant from the small zone is likely to turn out indifferent. Thus is illustrated the thesis according to which characteristics other than mechanical strength may possibly serve as standards of quality. As a matter of fact, the small area m, n, p, q, previously defined (Fig. 3), is found, according to the statistical graph (Fig. 4) to encroach upon the left of the theoretical limit of the ferrite and cementite spheres. This fact need not surprise us. In the first place, the diagram referred to is merely a simplified figure, of which too much ought not to be required.

Now the metals with which we are concerned are not in any sense alloys in a state of equilibrium, and therefore their properties ought not to be considered from too absolute a point of view. Moreover, the diagram does not take into consideration certain influences, in particular that of the manganese, silicon, and phosphorus, which, it is quite certain, modify—other things being equal—certain properties, either mechanical or physico-chemical. On this latter point we think we may lay it down—and this is the result of several hundred tests—that the limit of the ferrite and cementite spheres (the line EY in Fig. 2) is displaced towards the left when certain elements are added to the iron and to the carbon. The result of which is, for example, that a metal containing 3 per cent of total carbon, 0.73 per cent of combined carbon, and little silicon and manganese, will be hypo-eutectoid, as shown in Fig 4. That is, it will show under the microscope clusters of ferrite; while a metal containing 3 per cent of total carbon, 0.73 per cent of combined carbon, 2 per cent (approximately) of silicon, and 0.50 per cent (approximately) of manganese, will be hyper-eutectoid; that is, it will show under the microscope elements of cementite.[5]

[5] This means that the carbon content of the eutectoid is not fixed definitively at one sole value but, on the contrary, varies concomitantly with certain additions. It is known, moreover, that chromium, when large additions of it are made to steel, appreciably diminishes the carbon content of the eutectoid.

In any case it is beyond question that the diagram submitted by M. Portevin is of great interest from the practical point of view (this is proved by the example cited) and that it may be of considerable service.

We shall, however, discuss later on the points of interest in regard to the analysis of the products cast and their micrographical examination.

As it is the purpose of this paper to deal with the methods of testing cast iron, it would be out of place here to touch upon the manner in which our system of manufacture was developed, the object of this development being—as already mentioned—economy in the use of raw materials and, simultaneously, the improvement of the physical properties of the products. We shall confine ourselves to stating that our efforts were quickly crowned with success. We were able regularly to produce machinery castings of the most varied dimensions and weights, sound in every respect, free from stresses, homogeneous, composed of metal with a pearlitic base, and showing shearing strengths (to which method of testing allusion will be made later) invariably ranging from 28 to 32 kg. (39,824 to 45,515 pounds per sq. in).

Testing Methods Examined

We now propose to describe briefly the experimental details of the methods adopted.

It is impossible, within the limits of this paper, to reproduce all the important matter which appears in the original memoirs (see bibliography at the end of this paper), in particular those written by M. Fremont and those from the pen of M. Portevin.

The perusal of these notable works, written by masters whose competence and renown extend both to metallurgy and testing practice, will be of interest to all who concern themselves with the question dealt with in the present paper, and indispensable to those who wish to form a sound opinion on the matter.

The monographs communicated by M. Ronceray, whose name is connected with so many discoveries of interest to foundrymen, and who, with a disinterestedness worthy of all praise, has effected the construction of small testing machines, will also be read with great interest. Finally, much profit will be derived from the

studies of M. Thyssen, of the Compagnie Générale des Conduites d'Eau, in Liege, who has improved the experimental conditions of testing.

Our personal documentation is based upon the execution, in the course of over four years and during uninterrupted manufacture, of several hundred groups of tests (or several thousand individual tests) relating to castings, such as the casings of marine turbines, large cylinders or pistons for Diesel engines, etc. (Fig.

FIG. 5

5). The production of these castings represents a very large amount of labor, and their rejection, especially on account of inadequate mechanical strength, would be a particularly vexatious mishap. As a matter of fact, we have never had to record a rejection on account of deficient strength, and the rejections for other reasons—for example defects in castings—are extremely rare, as very special precautions are taken to prevent them.

During the first period of experimental study the testing methods employed for controlling the quality were the shearing test, the compression test, the ball test, static bending test, micrographical examination and chemical analysis. It may be thought that this is excessive, and we readily agree; a selection had to be made, and the methods which we ultimately decided to adopt will be mentioned later. All the tests, it may at once be stated, were carried out on test pieces taken from the casting in a sufficient number to enable its principal areas to be examined. For this purpose, at the time of casting, bosses were retained as part of the casting, the dimension of which along the axis was a few centimeters, while the other dimension (cross section) was approximately the thickness of the casting; the test piece was then taken in the vicinity of the junction of this boss with the casting, and it might therefore be presumed, up to a certain point, that the characteristics obtained from the test piece would also apply to the casting. It may be pointed out, in the first place, that the mass of the boss-test piece is very small in relation to that of the casting, and that consequently its thermal history should approximate very closely to that of the casting. Moreover, the ball tests carried out on the test pieces and on the castings after planing always confirmed the suitability of this method of operation; in addition, the use of the small model Frémont machine subsequently enabled us to become independent of the hypothesis of identity between the casting and a separate test piece, as the test pieces were then taken from the castings themselves.

Shearing Test

This test was devised by Frémont as a reception test for the finished castings. As a knowledge of the breaking strength was necessary, and as the tensile test was inconvenient to carry out and uncertain in its results, the author was led to consider the shearing test. His studies on the subject of the shearing of steels, the first results of which are to be found in a report to the Académie des Sciences (December 10, 1894), led him to the conclusion that there is a close relationship between rupture by shearing or by punching and the action of simple fraction. It was, therefore, reasonable to replace the tensile test, which, for special

reasons of expediency, could not be suitably applied to cast iron, by the shearing test, which was capable of producing a similar result, and one more practical from the experimental standpoint.

Frémont does not regard a testing method as good unless the classification of the tested products obtained by it is in conformity with that which should result in actual use. In carrying out his studies regarding the validity of the test advocated by him, he began by selecting 110 pieces of cast iron, the origin of which was as diverse as possible, and of which the results in use were known to him. He had tested these pieces by the shearing method and found that the castings known to be good showed great strength and the bad castings a low degree of strength. The method was therefore correct, subject to these first tests being confirmed by still more extensive experiments.

We have ourselves long made use of the test on test-pieces

FIG. 6

with a section of 8 x 10 mm. (0.315 x 0.394 in.) inserted broach-fashion in two complementary castings shown in Fig. 6, stressed by a tensile machine moved by hand. The operation was conducted sufficiently slowly to prevent it from being disturbed by any shock; in addition a series of Belville washers was used as shock absorbers. To prevent any relative displacement other than pure and simple longitudinal motion, a well-oiled bronze slide was employed to hold the two bearings of the test-piece. It is to be noted that if the two bearings are not perfectly adjusted in relation to each other and to the test-piece—and this means that their edges must be very hard—ruptures by bending are observed within the bearings themselves previous to the shearing proper. These ruptures cannot be confounded with those associated with the shearing, which separates cleanly the two pieces in the apparatus.

This method of operation has always proved satisfactory; the test is rapid, uniform and economical. The device described has the advantage of being capable of adoption in any laboratory which has available a tensile test machine of the simplest type. It has, however, the drawback of requiring—at least in principle—test-pieces of relatively large section, otherwise only a very limited portion of the scale of the machine can be used, if, as is generally the case, its capacity is from 10 to 30 tons. It is difficult, therefore, to take the test-piece from the very centre of the castings to be tested.

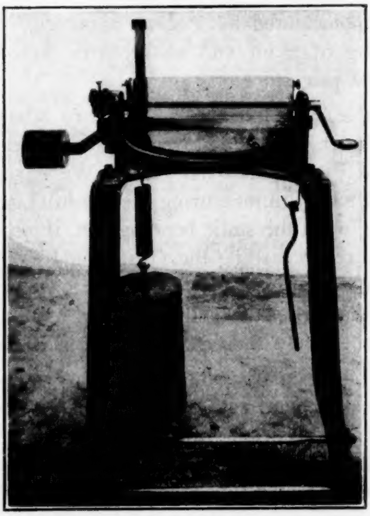


FIG. 6a—FREMONT SHEAR TESTING MACHINE

For this reason, instead of this apparatus we have been led to prefer the small Frémont machine which uses smaller test-pieces, measuring 5 x 5 mm. (0.197 in.) or 5.65 mm. (0.222 in.) round (section 25 sq. mm.) (0.3875 sq. in.). This machine, which is shown in Fig. 6a, consists of a lever movable about a sharp edge, the longer arm of which supports a movable weight, while the smaller arm exercises pressure, through a hard blade, upon the test-piece, which is sunk into a hard block and into a recess

provided in the blade. The slow movement of the weight along the longer arm is obtained by means of a suitable mechanical device; while this movement is taking place a pencil carried by a small suspensory arrangement traces a diagram on a fixed sheet of paper. When the test piece breaks—the resistance point of the section to shearing having been reached—the lever falls and the pencil marks clearly the end of the test. The horizontal length of the diagram, by means of a suitably simple formula, then enables the shearing resistance of the test-piece to be registered.

This small machine is extremely convenient in service. Its reasonable price makes it suitable for use in the smallest foundries. It is supplemented by a small apparatus for taking test-pieces, consisting of a bit and an eccentric system devised for taking round test-pieces.

It is possible, as Thyssen has done, to adapt to this small machine a cylinder which will register accurately the shearing deformations of the bar and the loads. We have not done this, contenting ourselves with measuring the breaking load under shear, while depending upon the static bending test, if necessary, for any particulars required regarding the (restricted) elongation capacity of the cast iron. To sum up, we decided to regard the shearing test as the typical test—the simple test which should always be carried out immediately the castings reach a certain importance.

The test is particularly suitable for this purpose. The possibility of repeating the test on the same test-piece guarantees great experimental accuracy; the very simplicity of registration afforded by the machine ensures exceptional uniformity; the construction of the apparatus makes it almost impossible for it to be put out of adjustment; and the cost of making the tests is most moderate.

Compression Test

We made the compression test on a cylindrical test-piece 16 mm. in diameter and 16 mm. in height. It has the advantage of showing the accuracy which is customary in the measurements of works laboratories, for the testing machine is that used in the tensile tests, this being—when all is said and done—the usual basis in the equipment of these laboratories. But, on the other

hand, it has one disadvantage, namely that the breaking load by compression of such a bar as described above is very high—approximately 18 to 20 tons for a good machine cast iron—which renders necessary a machine of somewhat considerable capacity, the immobilization of which to fulfill the requirements of compression tests may prove inconvenient if the number of tensile tests required daily is large.*

It was precisely this consideration that led us to abandon the method of classifying cast iron by means of the compression test, although this method appealed to us, after having had the experience of a large number of tests, as being accurate, uniform and economical. We shall give later on a survey of its comparability with the method which employs the shearing test, but we desire forthwith to state our conviction that the two methods are practically equivalent in regard to results. In other words, we have always found that the quality of a machine casting as indicated by the result of the compression test was the same as that indicated by the shearing test.

It is easy to understand why the compression test should give results normally correct and uniform. The metal is an alloy, practically characterized by the fact that the elongation (or the contraction) on rupture is practically nil, the elastic limit and the breaking load being almost equal. The compression test-piece of cast iron shows a clean rupture, and the completion of the test is clearly apparent. Moreover, under the conditions already mentioned, no disturbances need be feared, such as bending, shock, or buckling, causing the test-piece to break prematurely. The tensile test of cast iron, as is known, is not accompanied by the same accuracy, and it is desirable that too much credit should not be attributed to it, unless subject to special precautions which are not possible in a foundry laboratory. It must also be noted that the compression test, in the case of materials possessing a certain malleability, is a matter of practical difficulty, as the test-piece is crushed and flattened between the bearer plates, even blocking them to such an extent that it is impossible to observe a clean breakage.

*A smaller test-piece might, of course, be selected. In any case, the simple course is still to adopt the shearing test.

It is generally observable that the compression test-piece of cast iron is qualified by a species of shearing along elements of surface of which the tangential planes are inclined at an angle of 45° to the axis of the test-piece. (*Cf.* Strength of Materials, maximum angular slip). Frequently, indeed, an envelope consisting of a congeries of these planes forms a cone with an apex angle of 90°, having as its axis that of the test-piece and which is visible after the test.

Static Bending Test

"The experience of more than a century," writes Frémont,** "has shown that the static bending test is very instructive in regard to the quality of cast iron; that is to say, those metals which have given good service in use show a high figure under this test while, on the other hand, those of bad quality in use show a low figure." It was for this reason that he invented a machine which enables small test-pieces, which can easily be taken from any portion of the casting to be examined, to be tested with accuracy. The test-piece, which is a prism of 8 mm. x 10 mm. x 35 mm. (0.315 x 0.394 x 1.378 in.), is placed on two supports 30 mm. (1.181 in.) apart. A knife, actuated by a spring pressed by a screw, exercises pressure upon the middle of the test-piece. The screw itself is subjected to longitudinal motion by means of a hand-wheel. The effect of the intermediate spring is to transmit the stress gradually and without shock, for a very slight live force is sufficient to break the best test-piece. When the test-piece breaks with a deflection which is a fraction of a millimetre, the bend of the spring generally amounts to from 10 to 20 millimetres, which corresponds to several turns of the hand-wheel.

A device designed for the purpose enables a diagram of large size to be traced automatically, on which are recorded the successive indices of the load and deflection. This flexion diagram, as Frémont has shown, is most instructive. A large number of tests has enabled him to lay it down that "cast iron has an elastic bending capacity which is very variable and, generally, greater in

**"Nouvelles méthodes d'essais mécaniques de la fonte" ("New methods of mechanically testing cast iron"). This monograph is an historical study of the question of testing cast iron, and is full of interesting particulars of the methods formerly employed in estimating its quality, and, particularly, in testing the strength of ordnance.

proportion as its breaking strength is less. Under the same stress, two test-pieces of the same dimensions, but of different strengths, will show different deflections; that of lesser strength will bend more, and thus it will have a greater bending capacity. It will therefore require, to produce this flexion, a greater amount of work, since the deflection will be greater, and this difference may vary from one to three-fold. This is a general law, for, although there may occasionally be discrepancies, they are neither sufficiently numerous nor, particularly, are they sufficiently important to invalidate this principle. This elastic bending capacity, inversely proportionate to the strength of the metal, explains the failure of the tensile tests of good metal" (Frémont: *Op. cit.*).

As already stated, for several years we have employed the Frémont bending test on the metals used in the production of parts of marine engines. The static bending test-bar should be taken from a boss retained on the casting when poured, unless special circumstances permit of its being taken from the very centre of the casting, which is rarely the case. As regards machining, it will be observed that, as lathe work is generally more convenient and less costly than planing (for example with the shaping machine), the static bending bar is more expensive than the compression bar. The static bending test, however, has one advantage, namely that it enables the elasticity of the metal to be conveniently estimated.

Owing to the nature of the information which it yields, the static bending test is, in our opinion, the most desirable—that which is best suited for indicating the quality of the metal.

We reproduce (Fig. 7), as a curiosity, the old Joëssel machine formerly used (from about 1860) for classifying cast iron. It is a static bending machine which used bars of 50 x 50 x 500 mm. (1.969 x 1.969 x 9.845 in.) cast separately. We show beside it the small bending Frémont machine, which requires bars of 8 x 10 x 35 mm. (0.315 x 0.396 x 1.378 in.). The proportions of the machines as well as those of the bars may be compared.

Ball Test

It is M. Portevin who showed the value of the ball test for classifying cast iron, particularly such as was used for the semi-

steel shells made during the last war. Our own tests have confirmed the value of this test.

We operate as a rule on the castings themselves, which are rough-cleaned with a few strokes of the file, and we generally use a portable Morin apparatus with which the ball test is effected by shock, the ball being pressed between the casting and a small steel stamp of known hardness. We have found that the Brinell hardness figures obtained in this way are of the same order as those obtained from the metal with a static machine. Moreover, we only look to the hardness test for information regarding the

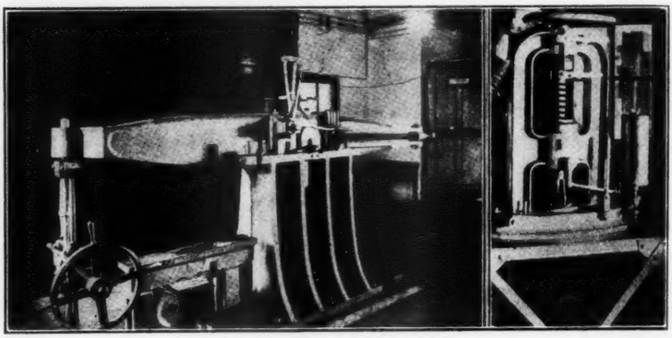


FIG. 7

homogeneity of the castings, and for this purpose we make hardness tests at widely divergent points so as to ensure a complete diagnosis.

Digression on the Tensile Test

Frémont and Portevin have both very clearly pointed out the objections to the tensile test in regard to cast iron under the conditions which are practicable in works laboratories. The test, being disturbed by circumstances inherent to the process itself, is lacking in uniformity, and should be abandoned, as the metal cannot suitably be classified by means of it. We have heard this proposal deprecated, and the following objections advanced on the subject:

(1) Its abandonment is very irksome: we can no longer make our calculations for strength of materials, for you do not now give us the tensile strength.

(2) Evidently your metal has no tensile strength, seeing that you do not care to test it.

(3) Why do you make no tensile test, notwithstanding the fact that in practice there are many examples of castings that have to work under tension and few that have to stand shearing stresses?

These objections might be easily refuted by saying, for instance, that there are few examples of castings working under tension pure and simple—few cases in which the stress is applied under the progressive conditions of the tensile test. It is fairer, however, to reply simply that the test selected ought to disclose one of those characteristics which we have termed "standards of quality," which are alone capable of enabling an accurate appreciation to be made. If this standard or criterion is well chosen it may justly be said that the metal is good if the result of the test is good, and conversely. The result of the tensile test is not a standard, precisely because the converse is not invariably true, for the metal may be good while the result of the test may not have been good owing to accidental causes. But this defect of the tensile test is of no importance, as we possess other means of seeing whether the metal is good or not, and this, after all, is the sole problem confronting us.

Micrographic Examination

Cast iron, like all alloys, is a crystalline structure. Now, in exactly the same way as the choice of materials and good quality masonry are the main sources of strength in an architectural building, the nature of the crystals, and the manner in which they are aggregated, constitute the fundamental factors in the strength of an alloy.

We must therefore examine the crystalline structure. The mere aspect of the fracture gives an expert valuable information, but microscopic inspection serves the same purpose, and with far greater uniformity and accuracy.

We may say at once that the microscopic examination of cast metals is an extremely simple matter. There is, unfortunately, too frequent a tendency to look upon the metallographic microscope as belonging to the aristocracy of laboratory instruments, and many foundrymen who will pay heavy expenses for labor or equipment in order to improve or even regulate manufacture would regard the purchase of such an apparatus as an unjustifiable extravagance. For our part we think—and this opinion is based upon documentary evidence embodying some thousands of experiments—that microscopic examination can be employed in everyday foundry practice with the most beneficial results. In the majority of cases, moreover, the average foundryman will find the ordinary metallographic microscope, without a camera, sufficient for his purpose.

The preparation of samples is a matter of only a few minutes, so that the method is at once extremely rapid and inexpensive.* If it is desired to keep a record of the structure, in order, for example, to make comparisons between various stages of manufacture with a view to ascertaining their uniformity and continuity, it is necessary to employ more complex apparatus, consisting of a microscope with a photographic attachment. In this case also, however, the method will prove to be economical, both in point of time and of money, and, as we shall see further on, also enables great uniformity and an unquestionably high degree of accuracy to be obtained in the observation of machine castings.

We have already pointed out those properties which, according to M. Portevin, constitute the structural characteristics of cast iron possessing high physical properties. We would refer the reader to the original memoir, already quoted, of this author, and will now proceed to consider the best method of micrographically examining machine castings.

Immediately after polishing, and before any etching, the sample should be carefully observed. The graphite will appear

*The "Précis de Métallographie microscopique, et de Macrographie" by Guillet and Portevin (Dunot, publisher) may be recommended as a guide for beginners and a reference book for microscopists.

in the shape of black filaments on the polished background. In addition there will be seen small cavities, of circular section, and likewise of a black appearance (microscopic blowholes and pipes). These are nothing else than fissures in the resistant material, the graphite by itself possessing no kind of cohesion. The greater the frequency of these breaks in continuity, and the greater their extent, the less will be the physical strength of the metal and the easier the machining. (For examples, see Figs. 8 and 10).

On further examination of the same polished and non-etched sample we shall see whether there do not occur small bluish-gray spots of geometrical outline. These spots betray the presence of manganese sulphide, a hard body which can make scratches in cast iron. A piston ring, for example, should not show signs of these small crystals; were they apparent, the cylinder in which it worked would quickly be worn out by scoring.

The polished surface should next be etched with picric acid. Two new constituents will then make their appearance, whereas the graphite will be masked.

The gray background is pearlite. This constituent belongs to the family of eutectoids—that is to say, it is composed of thin, juxtaposed laminæ—and is exceedingly hard. Properly speaking, except for the general dimensions of the laminæ, it is the normal constituent of very hard steels. Its cohesion, however, is in proportion to the fineness of its constituent elements. We will therefore examine it from this point of view, and will adopt the hypothesis that if the laminæ cannot be individually observed when magnified 120 to 150 times, the quality is good as far as pearlite is concerned.

The white spots seen on the gray background are either cementite (carbide of iron Fe_3C), or ferrite (noncarburized magnetic iron). In principle, cementite and ferrite are not found at the same time in the same metal. Cementite (which is replaced in highly phosphorous metal by another constituent, namely the triple eutectic which Portevin calls steadite) is fairly hard and brittle. It should not be present in excess, as too great a quantity gives rise to a tendency to decrease on the part of the physical properties, while the hardness becomes exaggerated and hinders

machining. The total absence both of cementite and ferrite would by no means be a bad thing, and the metal would then, properly speaking, be pearlitic. There is, however, a certain continuity of structure which classifies cast iron in the following order:

Cementitic iron, pearlitic iron, and ferrite iron.

Now, ferrite is a constituent the presence of which is attended by an appreciable decrease in the properties of the metal. In attempting, therefore, to obtain strictly pearlitic iron we should run the risk of involuntarily going too far, and obtaining ferrite iron. In conclusion, we may consider conditions satisfactory if we are able to detect the presence of a few isolated clusters of cementite, not too much spread out. This condition is not quite so desirable as the total absence of cementite, but it is much better than the presence of ferrite.

Both cementite and ferrite are visible, showing up white, after etching with picric acid. They may generally be distinguished by the fact that the edges of the clusters of cementite are clear-cut (steadite, which is related to cementite, and occasionally replaces it, usually has a concave contour and is spotted), whereas the outline of ferrite is indistinct. For greater security, the sample may again be etched, without being repolished, and this time with boiling picrate of soda. The cementite will then turn black (as also will steadite), while the ferrite will remain white. The final aspect must, therefore, reveal no trace of any white spots, as these would denote the presence of ferrite.

As we have already had occasion to observe, all the above mentioned characteristics have been pointed out by Portevin, who concludes his memoir ("Revue de Métallurgie," 1922) thus: "The micrographic examination of machine castings may provide valuable qualitative information when making researches with a view to obtaining certain determinate physical qualities. Hitherto, this method has been little employed, owing to the complex nature of cast iron and the multiplicity of variants which may intervene and modify its structure, but, if used with care and discretion, it seems clear that this process enables certain data to be obtained which it would be a mistake to disregard. . . ." Our task, therefore, consisted solely in investigating the question as to whether

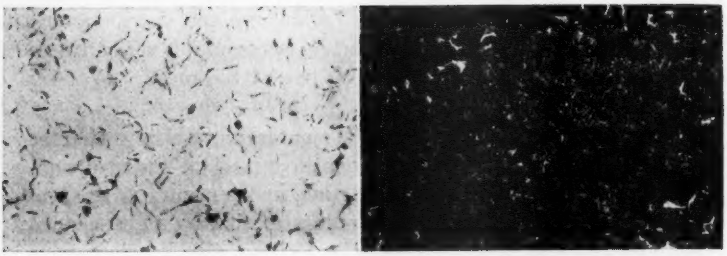
the standards of a micrographic nature laid down by the eminent author, and the application of which he only recommends with a certain reserve (owing to the complex structure of cast metal on the one hand, and absence of experience on the other), could be employed in the daily work of a foundry producing machine castings.

We think we may claim to have put the matter to the test, and only regret that the limits of this paper do not permit us to bear out our assertion by the large number of micrographs in our possession, and which clearly show the decided influence of the various structural elements (abundance and distribution of the graphite, fineness of the pearlite, presence of cementite or ferrite, etc.) on the physical properties of the metal. We will limit ourselves, therefore, to citing one or two examples.

Briefly, we may say that the appearance which should be presented by good machine castings in respect of the structural characteristics of the graphite, pearlite, and cementite, is easy to remember, and that the corresponding standard can be applied without any difficulty. This will be realized upon a comparative examination of the castings represented in Fig. 8, which afford convincing examples. One is astonished at the accuracy of the diagnosis based on a mere microscopic examination once a certain amount of practice has been acquired. In the domain we are exploring—that, namely, of machine castings—we consider the method one of the most rapid, inexpensive, uniform, and—we need not hesitate to add—accurate. It reveals the most minute variations of manufacture, and enables us to foretell with a great degree of accuracy the results of the mechanical tests. If micrographic examination cannot be admitted on a par with the measured tests considered authoritative for the reception of machine castings, it may at least be looked upon as capable of providing foundry engineers with a simple and efficient method for daily estimating the value of the product under manufacture.

Chemical Analysis

We have already pointed out how, according to Portevin, the knowledge of the percentages in machine castings of total carbon, graphite carbon, and combined carbon enables the degree

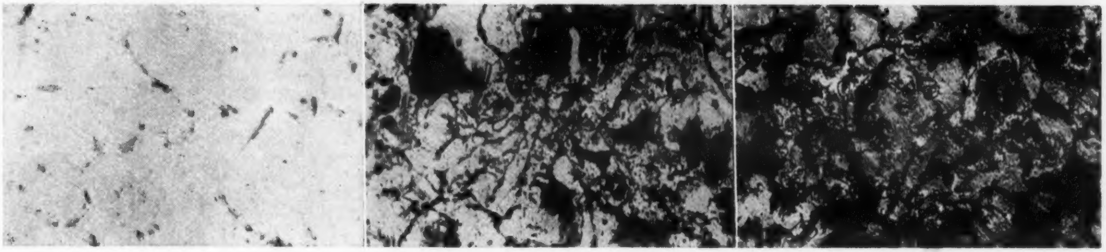


A B

FIG. 8 (a)—MICROPHOTOGRAPHIC APPEARANCE OF EXCELLENT IRON OF MACHINERY CASTING—SHEARING STRENGTH 30 KILOGRAMS PER SQUARE MILLIMETER—BRINELL HARDNESS FROM 210 TO 230—COMPRESSION STRENGTH 94.5 KILOGRAMS PER SQUARE MILLIMETER—CHEMICAL ANALYSIS: CARBON 3.05 PER CENT; SILICON 1.21 PER CENT; MANGANESE 0.75 PER CENT; PHOSPHORUS 0.20 PER CENT; SULPHUR 0.06 PER CENT. MICRO A NOT ETCHED SHOWING PARTICULARLY FINE AND WELL DISTRIBUTED GRAPHITE FLAKES. MICRO B, ETCHED WITH PICRIC ACID, SHOWING PEARLITE WITH A LITTLE CEMENTITE.

C D E

FIG. 8 (b)—MICROPHOTOGRAPHIC APPEARANCE OF IRON OF A GOOD MACHINERY CASTING (TURBINE CASING)—SHEARING STRENGTH 26 KILOGRAMS PER SQUARE MILLIMETER—BRINELL HARDNESS 210. MICRO C NOT ETCHED SHOWING SHORT LOOSE GRAPHITE FLAKES. MICRO D, ETCHED WITH PICRIC ACID, SHOWING FINE PEARLITE WITH VERY LITTLE CEMENTITE. MICRO E, DOUBLE ETCH WITH PICRIC ACID AND SODIUM PICRATE, SHOWS FERRITE ABSENT.



F G H

FIG. 8 (c)—MICROPHOTOGRAPHIC APPEARANCE OF A BAD MACHINERY CASTING (PUMP BODY, ORIGIN UNKNOWN)—SHEARING STRENGTH 19 KILOGRAMS PER SQUARE MILLIMETER—BRINELL HARDNESS 153. MICRO F, NOT ETCHED, NOT CLEAR. MICRO G, ETCHED WITH PICRIC ACID, SHOWING LITTLE PEARLITE, THE CEMENTITE AND FERRITE QUESTIONABLE; THE WHITE PORTIONS ARE PARTLY FERRITE AND PARTLY CEMENTITE. MICRO H, DOUBLE ETCHED WITH PICRIC ACID AND SODIUM PICRATE.

of mechanical strength to be foretold, at any rate approximately. By way of illustration, we have reproduced a statistical graph in which are grouped a certain number of castings of which the analyses and strengths were known to us, and which shows that those castings of which the total carbon and combined carbon contents are within the neighborhood of 3 per cent and 0.80 per cent respectively have every chance of turning out satisfactory, whereas castings the composition of which varies considerably from these figures are extremely likely to be inferior. Chemical analysis is, therefore, able to furnish information as to the actual merits of machine castings. In our opinion, however, it is not a method to be recommended, and that for the following reasons:

Chemical composition, although possessing a certain relationship to the powers of resistance of the metal, as pointed out above, cannot, however, be considered as an accurate standard, at any rate, not until a large number of conclusive experiments have been carried out. As a rule, it merely serves the purpose of an approximate guide as to the probable strength of the metal.

On the other hand, it cannot be denied that the methods of analyzing carbon are often extremely accurate. Unfortunately, however, these same methods are subject to disturbing influences which often escape the notice of the operators, and render them irregular. Finally, analysis is slower and more expensive than the mechanical tests recommended.

We consider that analysis is useful to the producer of machine castings, as it provides him with data which it would be impossible to derive from any other method. In the majority of cases it explains those variations in manufacture which are revealed by other means, and due to the introduction into the cupola of elements which have not been taken into account, either through inadvertence or ignorance, in calculating the burden. We do not consider, however, that analysis can legitimately be regarded as constituting an element in the reception of mechanical castings.

The question of raw materials is, of course, one which lies outside the scope of our subject, but we may say that in our opinion, for reasons which we will not go into here, chemical analysis should form the basis of any specification concerning them.

Relation Between the Results Given by Various Methods of Testing Machine Castings

We selected a certain number of metals, all containing about 3 per cent of total carbon, but with varying silicon and manganese contents. With these different qualities of metal, each contained in a crucible, we cast bars of progressive diameters, namely, 25, 40, and 60 millimetres (0.984, 1.575 and 2.362 in.). We cut the centre portions of these bars into a certain number of sections of which the homogeneity was ascertained by numerous ball tests. We then cut from these sections test pieces for shearing, com-

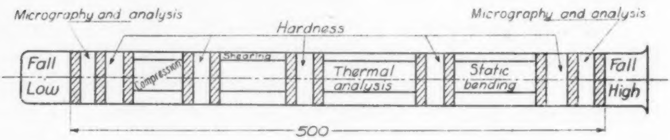


FIG. 9

pression, and static bending, and, further, made thermal analyses by means of Chévenard's industrial dilatometer, took micrographs, and made chemical analyses (see Fig. 9).

The rate of cooling is naturally the higher, the smaller the diameter of the bar, and, as is well known, this gives rise to variations in the properties of the metal. It may be expected that graphitization will generally be more pronounced in large bars than in smaller ones, and the physical properties will follow a progression inverse to that of the graphitization.

The micrographs (Fig. 10) show this progressive graphitization clearly. In the 25 mm. (0.984 in.) bar will be observed short and very fine filaments of graphite. In the 40 mm. (1.575 in.) bar these filaments are thickened, also lengthened, and in the 60 mm. (2.362 in.) bar they have become of considerable size.

In the next series of micrographs the distribution of the cementite and the fineness of the pearlite will also be observed. In the result, the preponderating influence is that of graphite. The strength of the 25 mm. (0.984 in.) bar should be good, that of the 40 mm. (1.575 in.) bar less, and, finally, that of the 60 mm. (2.362 in.) bar poor.

This probable hypothesis was verified by means of mechanical tests, the results of which are given in Table 1.

Table 1

(Reference F)

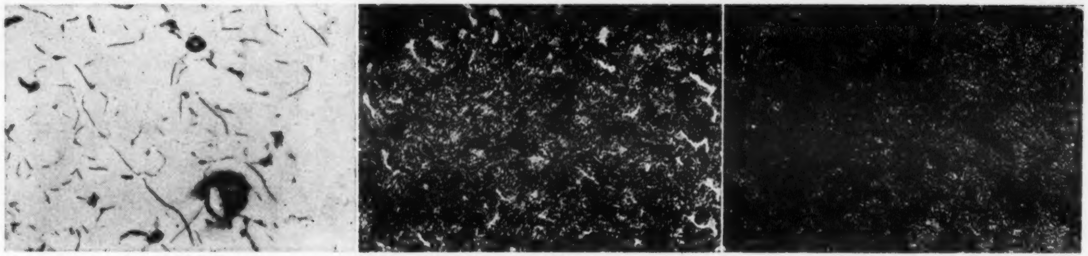
Observations	Bar of 25 mm. (0.984 in.)	Bar of 40 mm. (1.575 in.)	Bar of 60 mm. (2.362 in.)	Chemical Composition	Nature of Test
Average of 15 tests distributed over the length and section of the bar.........	228	213	195	Total Carbon,	Brinell Hardness
Extreme figures measured...	221-230	207-217	190-200	2.95%	
Pounds per sq. in..........	123,742	95,579	88,468	Silicon,	Compression
Kilos per sq. mm...........	87	67.2	62.2	1.22%	
Kilos per sq. mm...........	25.5	23.8	21.2	Manganese,	Shearing
Pounds per sq. in..........	36,269	33,851	30,152	0.54%	
Load in kilos..............	710	635	600	Phosphorus,	Static Bending
Load in pounds............	1,565	1,400	1,323	0.25%	
Deflection in mm...........	0.30	0.35	0.35	Sulphur,	Static Bending
Deflections in in............	0.0118	0.0138	0.0138	0.03%	

Further, the thermal analyses made by means of Chévenard's industrial dilatometer (in the absence of a differential registering dilatometer, which we did not possess at the time), gave us curves the useful portions of which are shown in Fig. 11. It will be observed that the amplitude of the dilation which takes place on cooling is the greater, the more nearly the metal approaches the ideal type defined by Portevin, i. e., graphite in loose filaments, and fine pearlite. This dilatometric phenomenon has been noticeable throughout our experiments, and we are continuing to investigate it.*

The parallelism existing between the results of the different experiments can be clearly seen.

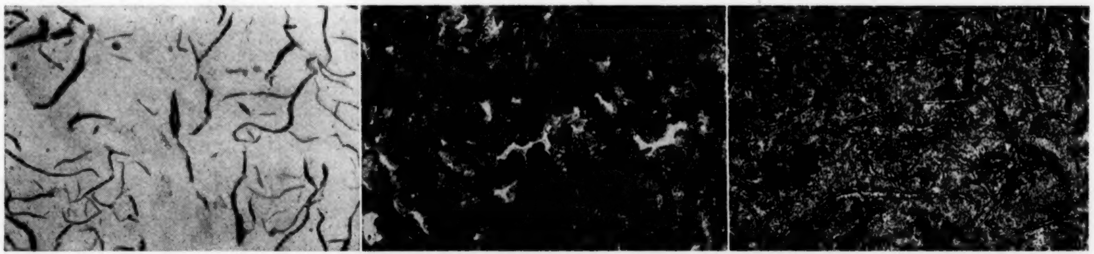
The example quoted is not an isolated one, and we could

*Messrs. Portevin and Chévenard are submitting to the Congress a Memoir upon the Dilatometric Study of Cast Iron. Confer Trans. A. F. A., vol. 34, pp. 767-808, 1927.



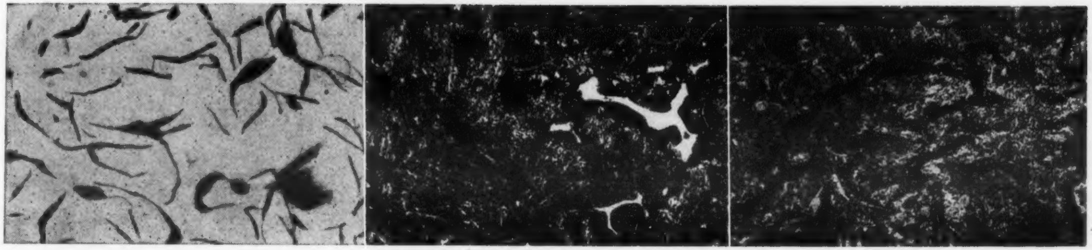
A B C

FIG. 10 (a)—BAR OF 25 MILLIMETERS—HARDNESS 228—SHEARING STRENGTH 25.5 KILOGRAMS PER SQUARE MILLIMETER—COMPRESSION 87—STATIC BENDING 710—CAST FROM A CRUCIBLE OF IRON OF TOTAL CARBON 2.95 PER CENT, SILICON 1.22 PER CENT, MANGANESE 0.54 PER CENT, PHOSPHORUS 0.25 PER CENT, SULFUR 0.03 PER CENT. MICRO A, UNETCHED X 200 SHOWING SHORT LOOSE GRAPHITE FLAKES. MICRO B, ETCHED WITH PICRIC ACID X 120, SHOWING PEARLITE OF MEDIUM FINENESS WITH RARE SMALL STRETCHES OF CEMENTITE. MICRO C, DOUBLE ETCH WITH PICRIC ACID AND SODIUM PICRATE X 120, SHOWING FERRITE ABSENT.



D E F

FIG. 10 (b)—BAR OF 40 MILLIMETERS — HARDNESS 213 — SHEARING STRENGTH 23.8—COMPRESSION 67.2—STATIC BENDING 635—CAST FROM SAME CRUCIBLE AS BAR OF 10 (a). MICRO D, UNETCHED X 120, GRAPHITE FLAKES MORE DEVELOPED THAN IN 10 (a). MICRO E, ETCHED WITH PICRIC ACID X120, PEARLITE OF MEDIUM FINENESS WITH A FEW STRETCHES OF CEMENTITE. MICRO F, DOUBLE ETCH WITH PICRIC ACID AND SODIUM PICRATE, FERRITE ABSENT.



G H I

FIG. 10 (c)—BAR OF 50 MILLIMETERS—HARDNESS 195—SHEARING STRENGTH 21.2—COMPRESSION 62.2—STATIC BENDING 600—CAST FROM SAME CRUCIBLE AS BARS OF 10 (a) AND 10 (b). MICRO G, UNETCHED X 120, THICK GRAPHITE FLAKES. MICRO H, ETCHED WITH PICRIC ACID, PEARLITE OF MEDIUM FINENESS WITH STRETCHES OF CEMENTITE (OR STEADITE). MICRO I, DOUBLE ETCH OF PICRIC ACID AND SODIUM PICRATE X 120, FERRITE ABSENT.

cite many other cases. Table 2 gives the results of tests analogous to those we have just dealt with, and what we have said above could in all respects be repeated in regard to each of the metals

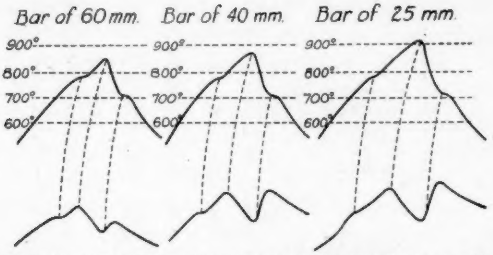


FIG. 11—THERMAL ANALYSIS OF BARS BY THE CHEVENARD INDUSTRIAL DILSTOMETER—LEFT CURVES OF BAR OF 60 MILLIMETERS—CENTER CURVES OF BAR OF 40 MILLIMETERS—RIGHT CURVES OF BAR OF 25 MILLIMETERS—THE UPPER CURVES REPRESENT THE DILATATION OF THE STANDARD NEEDLE, SHOWING THE TEMPERATURES—THE LOWER CURVES REPRESENT THE DILATATIONS OF THE SAMPLE—CHEMICAL ANALYSES GIVEN BELOW:

Chemical Composition Per Cent	Nature of Tests	Bar of 25 mm.	Bar of 25 mm.	Bar of 60 mm.	Remarks
Total Carbon 2.95	Brinell Hardness	(a) 228 (b) 221-230	213 207-217	195 190-200	(a) Arrange of 15 tests distributed over the length and section of bar. (b) Extreme figures secured.
Silicon 1.22 Manganese	Compression	87	67.2	62.2	Kilograms per square millimeter.
Phosphorus 0.25 Sulfur 0.03	Shear	25.5	23.8	21.2	Kilograms per square millimeter.
(Reference F)	Static Bending	710 0.30	635 0.35	600 0.35	Load in kilograms. Deflection in inches.

tested. We have not, however, reproduced the corresponding micrographs, owing to the large amount of space they would take up. We may simply state that the aspects observed are similar to those we have just examined, and that, in particular, the thickening of the laminæ of graphite, clearly observable, is a concomitant of the decrease in physical properties.

Table 2

Nature of the Tests	Reference E			Reference G			Reference H			Reference J			Reference K			Reference L			Reference M		
	C = 3.07			C = 2.93			C = 2.97			C = 2.91			C = 2.94			C = 2.92			C = 2.92		
	Si = 1.02			Si = 1.19			Si = 1.61			Si = 0.98			Si = 1.19			Si = 1.46			Si = 1.30		
	Mn = 0.54			Mn = 0.46			Mn = 0.40			Mn = 0.79			Mn = 0.80			Mn = 0.77			Mn = 0.97		
	P = 0.25			P = 0.28			P = 0.26			P = 0.25			P = 0.24			P = 0.20			P = 0.20		
	S = 0.06			S = 0.07			S = 0.07			S = 0.06			S = 0.03			S = 0.05			S = 0.04		
	Bars of: mm.			Bars of: mm.			Bars of: mm.			Bars of: mm.			Bars of: mm.			Bars of: mm.			Bars of: mm.		
	25	40	60	25	40	60	25	40	60	25	40	60	25	40	60	25	40	60	25	40	60
	Inches			Inches			Inches			Inches			Inches			Inches			Inches		
	0.984	1.575	2.362	0.984	1.575	2.362	0.984	1.575	2.362	0.984	1.575	2.362	0.984	1.575	2.362	0.984	1.575	2.362	0.984	1.575	2.362
Hardness, Brinell number	228	205	190	232	213	187	225	214	201	245	230	222	230	217	198	229	208	190	227	199	187
Compression load, kg/mm.^{2}	78.1	69.7	62.7	79.1	72.6	59.2	88.9	76.6	71.1	97.6	89.2	86.1	79.6	77.1	74.1	76.6	70.0	66.6	76.6	63.0	55.5
Pounds per sq. in.	111,083	99,136	89,180	112,506	103261	84,201	126,444	108,950	101,127	138,818	126,871	122,462	113,217	109,661	105,394	108,950	99,563	94,726	108,950	89,606	78,939
Shearing load, kg/mm.^{2}	27.4	25.8	22.6	25.9	19.9	18.6	27.4	22.2	21.8	30.8	27.6	24.8	27.0	24.5	22.6	28.0	22.9	18.4	22.6	21.3	20.1
Pounds per sq. in.	38,971	36,696	32,144	36,838	28,304	26,454	38,971	31,575	31,006	43,808	39,255	35,273	38,402	34,846	32,144	39,824	32,571	26,170	32,144	30,295	28,588
Static bending, kg/mm.^{2}	700	685	650	705	610	540	810	710	610	900	780	720	900	825	780	710	680	600	800	690	670
Net tons per sq. in.	497.8	487.1	462.3	501.4	433.8	384	576	504.9	433.8	640	554.7	512	640	586.7	554.7	504.9	488.6	426.7	568.9	490.7	476.5
Deflection, mm...	0.35	0.30	0.30	0.30	0.28	0.30	0.33	0.30	0.30	0.31	0.35	0.35	0.30	0.30	0.30	0.30	0.30	0.35	0.32	0.30	0.30
Deflection, inches	0.0138	0.0118	0.0118	0.0118	0.0110	0.0118	0.0130	0.0118	0.0118	0.0122	0.0138	0.0138	0.0118	0.0118	0.0118	0.0118	0.0118	0.0138	0.0126	0.0118	0.0118

But we have a still vaster and yet more instructive source of knowledge—that which has been acquired as a result of the numerous tests which we have carried out in order to check our manufacture during the course of several years. The observations made have invariably confirmed the parallelism of the results obtained by the different methods referred to above. If, for example, micrographic examination revealed an excess of cementite, we may be quite certain that the metal would be overhard, rendering machining difficult, and that at the same time the shearing strength would be high. The metal having been cast in a dried mold, without chill, there was only one possible explanation—i. e., faulty chemical composition. Analysis will confirm this by showing, for example, an excessive manganese content. The evil will definitely have been brought to light, and its origin ascertained, so that it should be a simple matter to prevent its re-occurrence.

Can the parallelism which exists between the different methods of testing be expressed mathematically? In other words, are there any algebraical relations which correlate the results obtained by employing these different tests?

Portevin has suggested the following formulæ, which approximately unite the various physical properties: Compressive strength $= 2.5$ tensile strength $+ 18$ (small number of tests) Tensile strength $= 0.2\,\Delta - 13$ (few tests, but in marked agreement). Compressive strength $= \frac{\Delta}{2} - 5$ (large number of tests).

These three equations combining three variables should be such that one can be algebraically deduced from the other two. This is not the case, and we therefore at once see how we ought to regard these formulæ, or others, such as the following, which result from our own tests (see Fig. 12).

$$\text{Compressive Strength} = \frac{3}{5}\,\Delta - 54.$$

$$\text{Shearing Strength} = \frac{\Delta}{5} - 19.$$

$$\text{Compressive Strength} = 3\ \text{Shearing Strength} + 3.$$
$$\text{Tensile Strength} = 0.9\ \text{Shearing Strength} - 1.$$

These are convenient formulæ, capable of indicating the magnitude and the probable value of any particular characteristic corresponding to a method of testing which it has been impossible to apply, although other experiments have been made. The experience gained from a large number of tests authorizes us to accept

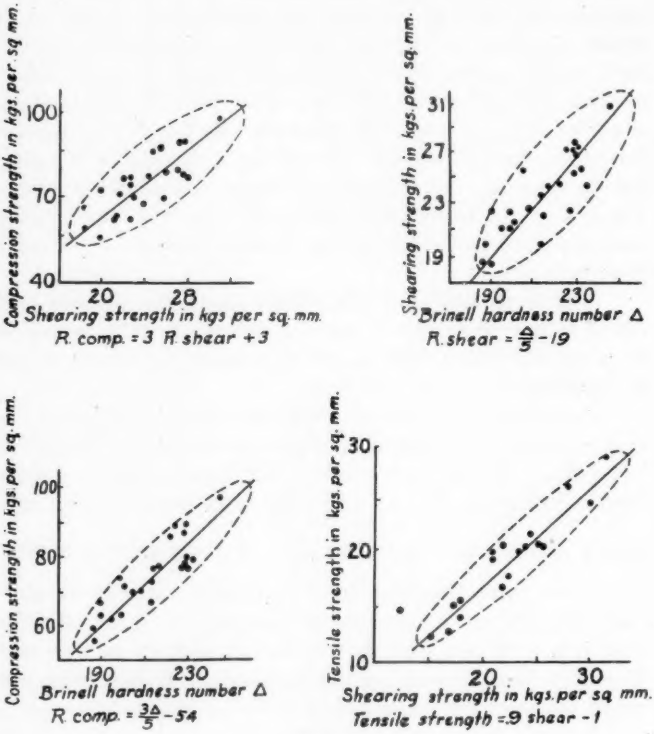


FIG. 12

this point of view as being correct, and we propose to interpret it as follows:

Let us classify machine castings by means of the shearing test in a certain number of categories, for example: excellent (above 26 Kg.), good (from 23 to 26 Kg.), medium (from 19

to 23 Kg.), and inferior (below 19 Kg.). Then, by means of the above formulæ, let us try to find the compression strength values which correspond to the limits we have just defined for the shearing strength, from which will result a quality scale in accordance with the compression strength, i. e.: excellent (above 81 Kg.), good (from 72 to 81 Kg.), medium (from 60 to 72 Kg.), and inferior (below 60 Kg.). Finally, let us subject a metal both to a shearing and compression test, taking all necessary steps to ensure that the quality of the test pieces shall be the same (by cutting them from neighboring sites and from homogeneous castings, etc.). The two figures thus obtained will not entirely satisfy the above equations, but their qualitative purport will be the same in regard to both tests. For example, we shall find that the alloy should be classified under the heading "Medium Castings" in both scales.

Here is another example of the application of these formulæ. Let us suppose that we wish to ascertain the maximum shearing strength which can be obtained from machine castings. If we try to obtain a metal of very great strength, we are soon stopped by the difficulty of machining. The metal becomes so hard that even the best tools fail to work it. We have measured the brinell hardness of a metal at the limit of possibility of machining and found it to be about 270. Applying the equations indicated above, we find that the corresponding shearing strength is 34 kg. per sq. mm. In practice we ought not to count upon exceeding this figure, nor even reaching it, for it refers to the crust of the casting, and the interior part is less hard and possesses less shearing strength.

Tests Made With Test-pieces Cast Separately

We have given above particulars of tests made with test-pieces taken from bars of progressive diameters, namely 25, 40 and 60 mm., cast from metal obtained from the same crucible. We found that the properties obtained varied in accordance with the diameter of the bar (see Table 2); and the graph (Fig. 13) reproduces, by way of example, the variations in the shearing strength of some of these machine castings. The variation is rapid, and this applies also to the other characteristics, so that the test of an

isolated test-piece will have no significance unless the diameter of the bar from which it has been taken, and, in a more general way, the numerous circumstances which react upon the cooling, have been carefully ascertained.

In order that a test-piece may be equivalent from the point of view of strength to a casting poured from the same metal, it would therefore be necessary for the course of the cooling to be identical in both cases. Not only will this generally not be the case, but, what is worse, the various parts of the same casting

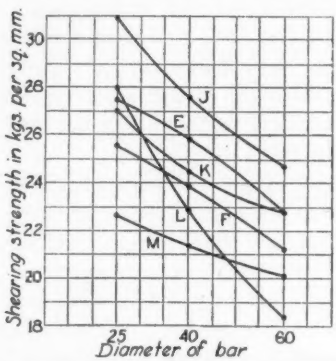


FIG. 13—SHEARING STRENGTH PLOTTED AGAINST DIAMETER OF BARS. FOR THE MEANING OF REFERENCES (M, L, F, K, E, J) SEE TABLE 2.

are subjected to different degrees of cooling. It cannot be expected, then, that the strength shown by the test-piece will be equal to that shown by the casting, nor can it even be expected that the different parts of the casting will really have the same strength. This complication is certainly very vexatious.

As regards the different parts of the same casting we may, however, apply a corrective to such elements in our argument as may be too strict. In the first place, it may be pointed out that as the different parts of the same casting are in thermal relation with each other, it will be possible for calorific exchanges to take place, and these will moderate somewhat the inequalities in cooling; moreover, the arrestation periods, and even the recalescences, occurring during the physico-chemical processes of transformation will also operate in the direction of making the

temperature uniform. Be it further noted that it is sound foundry doctrine to aim at equality of thickness in any given casting, if it is desired to avoid defects even more serious than inequality of strength, namely, the presence of internal stresses and the possibility of shrinkage (soufflures). The equalization of thickness will generally promote equality in cooling and, consequently, equality in strength.

Those conditions which tend to produce homogeneity of strength in the different parts of a particular casting can have no influence on the inequality of strength in the casting and the test-piece. What matters to the engineer, however, is the actual strength of the casting, or rather the effective strengths in its different parts. This is why we are not advocates of the test with bars cast separately, such as we were in the habit of practicing a few years ago. We regard as a great step forward the substitution, in place of these bars, of a large number of small test-pieces—the testing of which is easy, accurate and economical—which are taken from different parts of the casting, and the testing of which permits of the casting being diagnosed wherever desired.

Bases of a Specification for Machine Castings

Putting into practice the experience thus gained, we drew up a specification which is used for the internal diagnosis of machine castings at the Indret works of the French Navy. We have entirely abandoned the tensile and shock tests and have adopted, in principle, the view that the test-pieces tested should be taken from the castings, the smallness of the new test-pieces making it considerably easier to obtain this condition.*

Unless directions are given to the contrary owing to special conditions** we leave entirely to the founder the method of molding, the system of casting, and all other details relating to the production of the casting, such as the arrangement and number of the risers and feeders, the mixture of the materials, etc. Per-

*In an old specification we read: "The separate casting of the test-bars may always be sanctioned by the inspectors when this does not cause practical difficulties in carrying out the work of the department." The obligation of casting adherent test-pieces was rather a safeguard against possible fraud by substitution than a precaution against the alloy of the test-piece not proving identical with that of the casting.

**For example, the piston heads of Diesel engines must contain very little phosphorus, otherwise they quickly crack, etc.

mitted variations of dimensions are fixed when the order is given.

The castings must be free from physical defects, such as blisters, porosities, pipes, cracks, etc., which would be detrimental to their use.***

The position of the test-bars is determined beforehand by the Inspection Department. Independently of the tests carried out on test-pieces, the metal is examined for homogeneity by means of the ball test. In the case of castings in series, test-pieces are taken from a limited number of castings from the same tapping, and all the castings are ball tested. The results obtained on the test-piece from the castings selected may be applied to the entire melt, provided the homogeneity ascertained by the ball test is sufficiently verified.

With the bar tests no account is taken of those test-pieces which are visibly unsound, even when the defects are recognized in the course of the tests. This concession, however, does not affect the rule fixing the number of tests to be carried out, for the rejected test-pieces must be replaced by an equal number of others taken in addition.

The machine castings for marine engines produced at Indret are classified, according to their purpose and the strength conditions required, in the following categories:

Extra-strong machine castings,
Strong machine castings,
Ordinary machine castings,
Castings for special purposes,
Common castings.

The first three qualities are defined in the following specifications. The castings for special purposes are defined in each particular instance, except in the case of some in fairly frequent use (piston rings, castings to be subjected to heat), the characteristics of which are determined once for all. The common cast iron, which is used in making castings in which the intrinsic value of the

***In addition, it would be advantageous to be able to safeguard against the possible existence of internal stresses. Unfortunately, it is practically impossible to detect the existence of such stresses, and still more so (if we may so put it) to measure them. To ask the foundryman to give a guarantee as to the absence of internal stresses cannot be anything but an unjustifiable demand, pending the discovery of a suitable experimental method. Such a discovery, if it is ever made, will mean an enormous advance.

metal is unimportant (machine tool frames, counterweights, stoves, etc.), is not subjected to test; it is sufficient that the castings in question shall be free from important defects liable to be detrimental in their use, and also that they shall be easily machined.

Machine Castings

The tests properly applicable to extra-strong, strong and ordinary castings are those described below:

Micrography and chemical analysis, the first by way of a rapid test intended for the foundry engineer; the second, as already stated, for the purpose of disclosing any possible irregularity in manufacture due to defective mixing; both being for the purpose of verifying the uniformity of manufacture over a period of time. The results of these tests are communicated to the inspector merely by way of information, and they do not directly determine acceptance or rejection; they merely enable a court of reference, as it were, to be set up in case the mechanical results should prove slightly deficient.

Mechanical tests—shearing, static bending and compression—which enable the metal of large castings to be classified as to quality very exactly.

Ball tests for hardness, which enable the homogeneity of large castings to be tested, and also the metal of small castings to be classified without any other test.

The shearing test is made either on a bar of 8 x 10 mm. (0.315 x 0.394 in.) or one of 5 x 5 mm. (0.197 x 0.197 in.), or else on a bar 5.64 mm. (0.222 in.) in diameter.

The static bending test is made on a bar of 8 x 10 x 35 mm. (0.315 x 0.394 x 1.378 in.).

The compression test is made on a cylindrical bar 16 x 16 mm. (0.630 x 0.630 in.).

These three tests are equivalent as far as quality testing is concerned; in the case of large castings, however, it is preferable to carry out static bending tests under the following conditions, which enable additional and more detailed data to be obtained, which are of service in the general conduct of manufacturing operations.

Special Conditions for Extra-Strong Machine Castings
(Castings subject to high stresses)

There shall be a chemical analysis for each lot of castings made from one pouring with the same alloy.

For each casting a micrographic examination shall be made of a fragment separated after casting, the dimensions of which shall have been so selected that the structure of the point examined shall be that of the casting in general.

Shearing tests shall then be made on test-pieces taken from each casting, either by boring in the casting itself, in parts which will ultimately be removed by machining, or, if this is impossible, by an adherent test-piece detached after stripping. The dimensions of these latter test-pieces shall be such that the fragments tested have the same structure as the casting in general. As each test-bar permits of several shearing-strength measurements, the average of the figures obtained in these tests shall be taken as the strength of the metal of the bar.

The number of tests relating to each casting shall generally be the integer immediately below the quotient of the weight of the rough casting in kilograms divided by 200, but this number may not be less than 2 or greater than 5. If it is equal to or greater than 3, for one shearing test-bar there shall be substituted a static bending test-bar, the material for which shall be allowed for when casting. The bars shall be distributed uniformly over the casting.

All the shearing test-bars must show a minimum average strength of 23 kilograms per square millimeter. The static bending bars must stand a load of at least 610 kilograms.

If necessary, for the preceding tests there may be substituted a compression test on test-pieces taken from the casting; the compression strength shall be at least 78 kilograms per square millimeter.

Ball tests distributed over the rough-cleaned casting, and sufficiently numerous to test its homogeneity, must show, as a general rule, a brinell hardness ranging between 160 and 230. But excessive hardness shall not entail rejection unless the metal is at the same time found impossible to machine, while deficient hardness shall not involve rejection unless a test made on a test-piece taken

from the immediate vicinity of the ball tests shows an average shearing strength below the permissible minimum.

Repair of Defects

Only defects of extremely slight importance shall be passed, and this only provided that they obviously cannot exercise any detrimental effect either on the strength of the casting or its efficiency in use. If they disfigure the appearance of the casting they may be repaired, but only by means of dowelling.

Special Conditions for Strong Machine Castings

There shall be a chemical analysis and a micrographic examination for each lot of castings made from one pouring with the same alloy. Shearing tests shall be made on each casting under the same conditions as those applying to extra-strong castings, except that their number shall be determined, as a general rule, by the integer immediately below the quotient of the weight of the rough casting in kilograms divided by 500, but this number may not be nil or over 5. If it is equal to or greater than 3, for one shearing test-bar there shall be substituted a static bending bar. All shearing test-bars must show a minimum average strength of 19 kilograms per square millimeter. The static bending bars must stand a load of at least 530 kilograms.

If necessary, for the preceding tests there may be substituted compression tests on test-pieces taken from the casting, which must show a minimum of 60 kilograms per square millimeter.

Ball tests distributed over the rough-cleaned casting, and sufficiently numerous to test its homogeneity, must show, as a general rule, a hardness ranging between 140 and 200, with permissible variations analogous to those indicated in the case of extra-strong castings.

Repair of Defects

Only defects of extremely slight importance shall be passed, and this only provided that they cannot exercise any detrimental effect either on the strength or the efficiency in use of the casting. If they disfigure the appearance, they may be repaired by dowelling or the insertion of special cement.

Special Conditions for Ordinary Machine Castings

For each lot of castings made from the same pouring there shall be, if practicable, a chemical analysis; whereas a micrographic examination shall be obligatory.

For each two castings in the total number of castings forming the lot, one shearing test-bar shall be taken. The two bars must show a minimum strength of 15 kilograms per square milimeter. Castings weighing over 100 kilograms shall be ball tested on rough-cleaned parts, and their hardness shall be above 130 and below 230 at every point.

Repair of Defects

Defects of slight importance may be passed, but only provided that they cannot exercise any detrimental effect either on the strength or the efficiency in use of the casting. They may be repaired by dowelling, special cement or the application of metal properly prepared.

Concluding Statements

The foregoing specifications govern our manufacturing practice, and we are in no way hampered by them. We even find in practice that, although we make extensive use of engineering scrap, our products generally show shearing strengths exceeding the prescribed minima by from four to six kilos.

It is obvious, of course, that these specifications are given here merely by way of example. They apply to machine castings which, as has been explained, must be very specially guaranteed owing to their use in marine engines. Other forms might be drawn up for other types of castings.

If the author, moreover, has dealt at length with the results arrived at in the works to which he is himself attached, this is because they were within his personal experience, and he was in a position to discuss them with full knowledge. It is nevertheless the fact that these are not the only works which have adopted the principle of the tests described in the present paper.

The important Compagnie Générale des Conduites d'Eau, of

Liège, Belgium, has for several years been alive to the great value of the ball, tensile, and shearing tests for purposes of determining quality. We have already mentioned M. Henry Thyssen, the head of that company's laboratory service, whose studies on the subject are of the highest value. The conclusion of one of these studies is that the control obtained by means of these methods, which permit of small fragments of the casting being tested, "presents a signal advantage over that obtained by using test-pieces cast in a separate mold. While this old method merely enables the quality of the metal used by the foundryman to be ascertained, the new methods enable an opinion to be formed regarding the quality of the castings that are to be delivered; while the one classifies the raw material, the other classifies the finished product."

It would be impossible to be at once more precise and more concise.

The great Paris-Orléans and Est railway companies have definitely begun to adopt the tests recommended. M. Audo and M. Dewe, who respectively direct the foundries of these two companies and who—to employ the expression of one of our friends who himself holds an important position in the Paris-Lyons-Mediterranean Company—are foundrymen possessing an unerring technique, the scientific spirit, and the progressive instinct, have carried out certain most interesting experiments for the purpose of ascertaining for themselves the value of the new methods of testing.

They obtained as a first result an important saving by the substitution of the shearing test for the tensile test, which enabled one of these gentlemen to write off in three months the cost of the small Frémont machine.

The ease with which the shearing test can be executed—being carried out on a tiny test-piece which can readily be taken from the casting—has enabled locomotive cylinders to be examined in every part. Once co-ordinated, the results obtained enabled M. Dewe to improve the methods of molding these castings, particularly by the elimination of the feeder, by which an appreciable economy in manufacture was achieved.

Other economies are anticipated similar to those which we

have ourselves realized, and which will accrue from a wider use of common raw materials.

The testing of the foundry products of the Paris-Orléans and Est companies is carried out according to the new methods. The inspection at the contractors' works still takes place on the old system. It may, however, be anticipated that in the near future the great French railway companies will adopt a specification similar to that drawn up by us, of which a summary has been given in this paper.

The French Minister of Marine himself intends to extend to all contractors supplying the Navy with machine castings the provisions of the specification at present obligatory at the Indret works.

We must also make mention of the researches made by Captain Planas, of the Spanish army, whose experiments were absolutely independent of our own. The meeting which took place between us on the occasion of the Foundry Congress of Liège in 1925 enabled us, however, to ascertain that our ideas on the subject were in perfect agreement.

It is somewhat remarkable, moreover, to find that the different experimenters who now recommend the adoption of the tests particularly described in the present memoir, worked in ignorance of each other's labors. The fact that their conclusions are very nearly identical greatly enhances their value.

It is no less remarkable that these testing methods, the purpose of which is a better knowledge of materials and, in the last resort, to safeguard the engineer, have found no more convinced adherents than foundrymen. For, while the investigators whom we have just mentioned have frequently—as in our own case—been engineers, it must be recognized that it has been the foundrymen, notably by means of their technical associations, who have encouraged the development of these methods by the publicity given to research, by their moral support, by the interchange of ideas in discussion, and by the co-ordination of efforts. Nothing could be more natural than that the engineer's dearest wish should be to discover the ideal specification which will ensure him the supply of good products. But nothing could be more gratifying

than that the producers themselves should be unwilling to rest until this ideal specification is adopted. These efforts cannot but redound to the honor of foundrymen.

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Discussion

J. W. Bolton: On page 715 the paragraph in the center of the page states: "The preparation of samples is a matter of only a few minutes, so that the method is at once extremely rapid and inexpensive. If it is desired to keep a record of the structure, in order, for example, to make comparisons between various stages of manufacture with a view to ascertaining their uniformity and continuity, it is necessary to employ more complex apparatus, consisting of a microscope with a photographic attachment." And the author goes on through the paper to stress that point of ease of preparation. As a matter of fact the preparation of samples for microscopic analysis of cast iron is one of the very most delicate arts which

the metallurgist or testing engineer has to deal with. The author is particularly interested in the distribution of graphite. It is well known that only the most careful workmanship will reveal the true graphitic structure. Cast iron is particularly susceptible to dragging in the polishing operation.

When examined in this dragged condition the flakes are shown drawn over and distorted. If we simply looked at it as a very simple matter and did not give the polishing a great deal of care and attention the results would be highly misleading. As a matter of fact, in commercial practice you too often find micrographs in which you cannot tell anything of the structure because of poor workmanship.

On page 716, at the top of the page, he says: "In addition there will be seen small cavities, of circular section, and likewise of a black appearance—microscopic blowholes and pipes. These are nothing else than fissures in the resistant material, the graphite by itself possessing no kind of cohesion. The greater the frequency of these breaks in continuity, and the greater their extent, the less will be the physical strength of the metal and the easier the machining."

Then just before that he says: "The graphite will appear in the shape of black filaments on the polished background."

That is not in full accord with very careful research work which has been done over a period of years. The late Professor Howe was the one to first point out that the graphite flakes are not mere cavities, that they have in them a network, presumably of ferrite. I have also found manganese sulphide, and other inclusions. Just to look at it in a common sense way, if we were to look at a micrograph of open grain cast iron we would see that the graphite flakes themselves offer almost no continuity. We would be forced to conclude that that material had practically no strength because of that fact—which is a false assumption. And, further, in speaking of the test piece having no significance, in this matter we really are talking the same language. One group is saying correlate because it is simple, it is more convenient, and it is a fact that a number of foundries in this country and quite probably abroad are able by the process of correlated knowledge and by their research and the detailed work they have done, to determine quite accurately the properties of the casting from the properties of the test bar.

If we consider the composition and the temperature of pouring and the rate of cooling as determined by the size of the section, it is quite well known that we can calculate the relative rate of cooling by a very simple expedient. If the casting temperature is somewhat similar (and that certainly should be the case if we are making a comparison) the heat in any given iron is proportional (i.e. the value in the B.T.U's is closely proportional) to the cubic content or volume of the bar or casting. The cooling rate is partly determined by this heat which must be dissipated. It is also determined by the surface area, the area of the casting or test piece, granting only this, that there is equal conduction in the mediums;

in other words (molding sand or core sand), in which the test bar or casting are cast. Therefore, you have a factor by which you can calculate the relationship of bar to casting, that is by the $\frac{\text{surface area}}{\text{volume}}$ ratio. We are also all agreed here I believe that the properties are very largely determined by the structure. The author points that out.

I have recently done some work in checking this factor of $\frac{\text{surface area}}{\text{volume}}$ in the casting as compared to the ratio in the test bars to see if we get the same structure, if the factor is similar, and I find we do.

Mr. Shepherd: Mr. Ronceray spoke about the fact that in the specification should be incorporated the location of the test specimen as determined by the point of the weakest part of that casting. Now I think specifications should be used pretty carefully, and the location of the weakest spot of the casting, I think, is pretty well known. And it can be changed materially by the method of gating. I would like to ask Mr. Ronceray whether there is any tentative suggestion as to the method of gating? As to whether the location of the test specimen is definitely pointed out?

E. V. Ronceray: I believe the tendency is to leave the foundrymen in full charge of the method of gating. Now I do not mean that the test must be taken at the weakest point. It may be that the weakest point is not an important part of the casting. It may be it is not absolutely necessary that the test be taken in the weakest part of the casting. It has to be determined where we want a certain strength, where the test has to be taken. The weakest part can be important, or that which is not the weakest part may be important.

Mr. Perry: Wouldn't it be just as well, if you are going to say where to take it, to find out where the greatest strain would come in the casting? The weakest part of the casting might be put entirely away from the greatest strain. But I think in a shop they don't know where the greatest strain is going to be. If it was specified where that was then the test bar could be taken from there. Then the foundrymen could make that the strongest point.

Chairman L. L. Anthes: It is quite true, gentlemen, that the different foundries have different practices as to where the test bar is taken from. It is a matter that is left more or less within the judgment of the foundrymen.

O. W. Potter: This discussion is indeed very interesting and does offer a new field for investigation. A great many of us are not entirely satisfied with some of the tests of cast iron. The transverse test has several handicaps. Just recently Francis B. Coyle of the Brooklyn Navy

Yard has given out some tests in which he shows that the elastic limit in compression of cast iron is very different from the elastic limit in tension, and that of necessity throws off the transverse test in the complicated arrangement.

In regard to the difficulty of using the machine and also the difficulty of getting proper alignment of the machine for making a tensile test, I think we find if we survey the whole situation that the handicaps for any of the tests are about on a par and we are looking for some kind of test which will more adequately represent the properties of cast iron.

With regard to the test bar being cast separate in the heat, I am inclined to believe that a separate test bar is a little better, for this reason. You have always the same relation of surface exposed to the value of material and then necessarily you can get more uniform conditions. It really is a problem of design rather than a problem of strength of material. For that reason I think the separate test bar is more desirable. But we are anxious to get some test which is a little bit more reliable than the shearing test, and I think it affords an opportunity for considerable investigation.

J. T. MacKenzie: I think a good deal of the arguments about test bars and tests from the castings have been under misapprehension. Any data obtained from test bars, unless it is correlated with the properties of the casting, determined experimentally or otherwise, would be of no value whatsoever.

Recently in the cast iron pipe field we have had some very exhaustive tests made on cast iron pipe, using small transverse specimens for the test 10 inches long and one-half inch wide, cut from the wall of the pipe; also, tensile bars of several kinds cut from the wall of the pipe in various places, and those were correlated, with bursting pressure, hydraulic bursting tests, with impact tests, and with cross bonding tests on the pipes themselves. Also, there were some ring tests made.

Now we do not propose to discard our test bar, because we do propose to make some tests on the pipes themselves. We propose to know the analysis of all the material going to the cupola. If we can determine all of that we have got the whole line. Then we come to the ladle and take six ladles out of 50 and pour test bars out of them and make an analysis.

Now we propose to take three to six pipes a day and make the small tests on them. Now if this line is straight and if the test bar line is straight and if the raw material line is straight, it is a good bet that all of the pipes are on that line. But it is lots easier for us to make a dozen test bars a day than it is to cut up a dozen pipes and we don't see any conflict in the two ideas.

Mr. Shepherd: I would like to ask Mr. Bolton what size castings he had found he could correlate the microstructure obtained in the test bar with the microstructure obtained in the casting? We experimented with the different alloys on castings weighing from 500 pounds to 3,000 pounds,

mostly up around 2,000 pounds, and we found there was absolutely no correlation between the results obtained on the test bar and the results obtained on the castings themselves. And, furthermore, castings in about that size, approximately a ton, we cast some in the molds with a temperature of 400 degrees Fahr and casting from the same ladle in a non-heated mold, with the pyrometer inverted in the flask so as to actually touch the little button on the surface of the metal, and in that particular case we found the mold which was heated cooled at a faster rate than the unheated mold.

And, furthermore, large castings, of identical analysis, made with the same type of charge, poured into the same size castings on different days, had absolutely different microstructure and physical properties. So it appears there is something else about which we do not know that has a very great influence upon the physical properties of cast iron.

J. W. Bolton: I might reply to that very briefly in this way: There is no correlation unless you correlate. To go further, these ideas in my case have been obtained on personal experience with castings of about 75 thousand pounds down to about 10 pounds. The reason you doubt the possibility of correlation is because you have not always had all the factors under control or have not recognized them. The same thing you admit in your statement there. You say one casting is different from another. I agree most heartily with you. No two castings are poured under identically the same conditions. That is a good reason for using test bars right there. Your castings would have to be the same design, the temperature as melted and poured, and in the same mold, under the same sand conditions at the same pouring rate, and there would be much more difficulty in accomplishing all that in commercial practice than in a standard test in the way of pouring several bars. And as we explained before we have used different sized bars, and compared with pieces cut from the casting. Our test bars have been from 0.5 inch diameter to 8.0 inch diameter. We used transverse, tensile, microscope, Brinell, shop tests and every kind we had available.

Here is one thing on which there seems to be quite a bit of misunderstanding between the advocates of test bars and those who say there is no relation between test bars and a casting. And I think I am speaking for every modern foundryman or metallurgist when I say that no one test can logically tell the whole story. There is no panacea for those troubles; you can't get something for nothing, you have got to go at it in several different ways, and use various tests, and correlate those tests with tests on castings themselves, and observation on actual service.

The Strength of Cast Iron in Relation to Its Thickness

By Willard H. Rother[1] and Victor Mazurie,[2]
Buffalo, N. Y.

Introduction

An accurate knowledge of the relationship existing between the strength and the thickness of cast iron is of paramount importance to all designing engineers, and it is most essential that this relationship be observed. In this paper the authors have given the results of a series of tests, conducted in an effort to determine some factor which would be an aid in calculating the true strength of gray iron castings of various thicknesses.

Theory

It has been known for many years that thick sections of cast iron were weaker per unit area than thin sections. This can readily be seen by comparing the fracture of a one inch bar with that of a three inch bar. The one inch section will show a fine, close, even fracture throughout, while the larger section will show a fine, close, structure, only near the surface. This variation is due to a difference in cooling rates. The interior of the small bar cools at a more rapid rate than the interior of the larger bar. Consequently, if unit areas are considered, it can be seen that the larger bar will not be as many times stronger than the smaller bar as the areas would indicate. It would then seem that cast iron does not follow the regular beam formulas as set down for steel. Actual test data, showing this difference in strength, have not been very abundant, however.

With these facts in mind, this investigation was undertaken to determine just how gray iron varies from the regular structural steel beam formula.

[1 and 2] Metallurgist and Assistant Metallurgist, respectively, of the Buffalo Foundry and Machine Company.

Procedure Followed in Investigation

General

The problem was approached in the following manner: By making a series of transverse tests on bars of different sizes it was thought it would be possible to obtain a relation between the thicknesses and the strengths, if all calculations were based on a standard value. The one inch bar of each heat was selected as the standard.

After making two sets of round bars it was found advisable to include square bars of the same dimensions in the following heats. This was done to determine the difference, if any, between the two shapes of castings.

From the size of the bar a section modulus was calculated

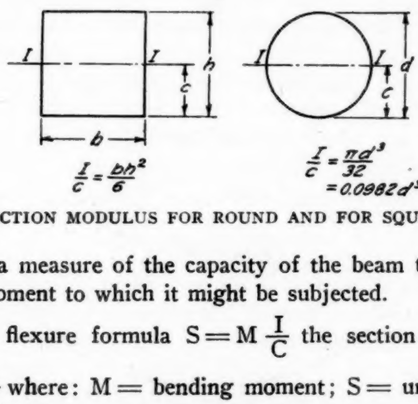

FIG. 1—SECTION MODULUS FOR ROUND AND FOR SQUARE BARS

which was a measure of the capacity of the beam to resist any bending moment to which it might be subjected.

In the flexure formula $S = M \frac{I}{C}$ the section modulus is equal to $\frac{I}{C}$ where: M = bending moment; S = unit stress on the fibre most remote from the neutral surface; C = the distance of that fiber from the neutral surface; and I = the moment of inertia. The formula for the section modulus is shown in Fig. 1 for both round and square bars.

By comparing these section moduli with that of the one inch bar, factors were obtained, which showed the theoretical proportion of strength which each bar should have as compared to a one inch bar. By multiplying the strength of the one inch bar by these factors theoretical strengths were calculated for

each size bar. The difference between this calculated value and the actual strength found in testing gave the per cent decrease in strength.

Casting of Bars

All bars used in these tests were cast in the following manner:

Fig. 2 shows the position occupied by the bars in the mold. A 1, 1½, 2, 2½, and 3 inch bar were cast in each mold and for each heat three sets of bars were made. All heats were cast in green sand molds, the metal being at a temperature of about

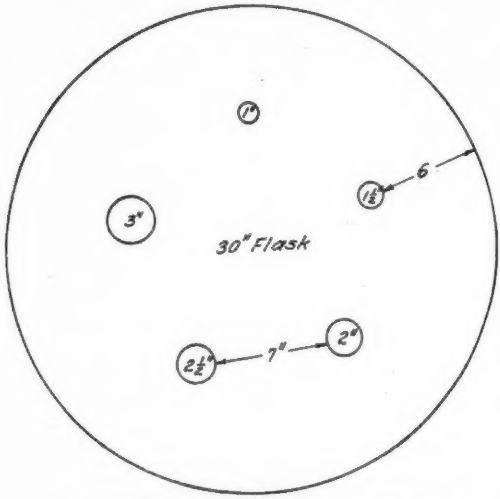

FIG. 2—METHOD OF CASTING BARS IN MOLD

2200 to 2400 degrees Fahr. The semi-steel was poured at the higher temperature.

The following morning the bars were removed from the mold, cleaned of sand and tested.

Transverse Testing

In making the transverse test the procedure was similar to that generally followed when using the A. S. T. M. arbitra-

tion bars. The bar was placed on supports 12 inches apart and the load applied at the center. The deflection in all cases was measured with dividers. Although rather crude, this method gives results which are comparable. All of the tests were made with an Olsen, hundred thousand pound, tensile testing machine, with the head moving at a speed of .05 inches per minute. This low rate of load speed was used to allow a more accurate beam balance on the larger sized bars.

Brinell Hardness

After breaking the bars in the transverse test, brinell hardness tests were made on the surface of each bar. Only sufficient metal was removed to provide a flat surface for the indentation. About the same area was prepared on all bars.

Transverse sections were then cut from one of each size of the round bars and the brinell hardness determined from the center to the surface.

In these tests an alpha brinell machine was used. The load applied was 3000 kilograms for 30 seconds. In measuring the depression, a calibrated microscope was used. Each value was the average of two readings of the diameter taken at right angles. The ball was the regular 10 millimeter diameter ball.

Tensile Testing

One bar was selected from each size of the round bars. These were turned into tensile test bars with a breaking section 0.875 inch in diameter and 2 inches long. It is self evident that all of the test pieces were turned from the weakest section of the bars; but it was felt that this would tend to show why bars of larger size failed to show the strength calculated. In applying the load the testing machine head moved at a speed of 0.30 inches per minute.

Microscopic Examination

In sampling for microscopic examination sections were selected about ¾ inch by ¾ inch by ½ inch. These pieces were taken from the center of the bar, as the most marked variation in structure would be apparent at that point. The samples were

polished in seven steps; coarse file, fine emery wheel, emery cloth No. 1, French emery cloth Nos. 0, 00, and 000, and final polish of rouge. After preparing the surfaces the samples were etched with 4 per cent nitric acid in methyl-alcohol and photographed with a Bausch and Lomb metallographic outfit.

Photomicrographs were made from heat No. 1, which was "Common Iron—2.15 per cent Si," and from heat No. 4, which was a semi-steel with 25 per cent of steel. The structure observable in all of the bars would be similar to those illustrated so that it did not appear necessary to show every structure. Only those of the two extreme heats were used.

Chemical Analyses

In making the chemical analysis the following method was used to obtain drillings. One bar of each size was drilled half way through and the drillings collected. After all the bars from a set had been drilled, the drillings were very thoroughly mixed and incorporated into one large sample. This was cut to a small sized sample by quartering and discarding opposite quarters until the desired size sample was obtained. Where square bars were cast the sample was taken solely from them.

In analyzing for the various elements the following methods were used:

Sulphur—Evolution, using cadmium chloride and titrating with iodine solution.

Total Carbon—Combustion, with a Fleming train having an Ascarite filled absorption bulb.

Phosphorus—Ammonium-molybdate method.

Manganese—Ammonium-persulphate method.

Graphite—Dissolve in 1.13 HNO_3. Heat gently till action ceases. Add few drops of hydrofluoric acid and heat till action ceases. Filter on counterpoised papers. Dry and weigh. Burn off paper and graphite. Weigh. Difference equals the graphite.

Silicon—A.S.T.M. method using a three acid mixture for dissolving.

Combined Carbon—Color.

The determination of total carbon by combustion was used as a check for the combined carbon and graphite determination.

Casting Data

Five sets of bars were used in making the investigation each set being composed of the following:

3 bars 1 inch diameter by 15 inches
3 bars 1½ inch diameter by 15 inches
3 bars 2 inch diameter by 15 inches
3 bars 2½ inch diameter by 15 inches
3 bars 3 inch diameter by 15 inches

In addition heats Nos. 3, 4 and 5 had a set of square bars as follows:

3 bars 1 inch by 1 inch by 15 inches
3 bars 1½ inches by 1½ inches by 15 inches
3 bars 2 inches by 2 inches by 15 inches
3 bars 2½ inches by 2½ inches by 15 inches
3 bars 3 inches by 3 inches by 15 inches

The metal used in casting the bars was designated as:

Heat No. 1—Common Iron.........2.15 per cent Si.
Heat No. 2—Semi-Steel............ 15 per cent steel
Heat No. 3—Common Iron.........2.10 per cent Si.
Heat No. 4—Semi-Steel............ 25 per cent steel
Heat No. 5—Semi-Steel............ 25 per cent steel

All bars comprising a single heat were poured at the same time from the same ladle. This eliminated any variation which might occur in the metal used.

Results of Chemical Analysis

On analyzing the composite sample from each heat the results given in Table 1 were obtained.

Results of Transverse Tests

Data found by the transverse test is given in Tables 2 to 9 inclusive and is shown graphically in Chart 1.

Results of Tensile Strength Determinations

Data obtained from the tensile tests is given in Table 10 and also shown graphically in Chart 1.

Table 1

CHEMICAL ANALYSIS OF HEATS

Average of two analyses

Heats	Per Cent Si	Per Cent Mn	Per Cent S	Per Cent P	Per Cent Combined Carbon	Per Cent Graphite Carbon	Per Cent Total Carbon
Heat No. 1 Common Iron	2.15	0.65	0.07	0.472	0.52	2.83	3.35
Heat No. 2 15 Per Cent Steel	1.70	0.85	0.11	0.442	0.68	2.85	3.53
Heat No. 3 Common Iron	2.10	0.60	0.10	0.345	0.54	2.98	3.52
Heat No. 4 25 Per Cent Steel	1.10	0.95	0.065	0.115	0.64	2.65	3.29
Heat No. 5 25 Per Cent Steel	1.20	0.90	0.11	0.310	0.70	2.70	3.40

Table 2

TRANSVERSE TESTS ON ROUND BARS—HEAT No. 1

Diameter in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.06 1.06 1.06	.1169	1	2050 2050 2100	2067	.....	0	.17 .16 .14	.16
1.57 1.57 1.57	.3799	3.25	6650 6200 5950	6267	6718	6.71	.15 .14 .13	.14
2.07 2.07 2.07	.8708	7.45	11700 13550 13550	12933	15399	16.01	.14 .10 .11	.12
2.56 2.56 2.56	1.647	14.08	25475 22350 24525	24117	29103	17.11	.12 .13 .14	.13
3.06 3.06 3.06	2.810	24.04	40850 38850 36300	38667	49691	22.18	.22 .13 .15	.17

Table 3

TRANSVERSE TESTS ON ROUND BARS—HEAT No. 2

Diameter in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.08 1.08 1.08	.1236	1	2475 2425 2150	2350	.....	0	.15 .12 .13	.13
1.605 1.605 1.605	.4060	3.28	7450 7750 6750	7317	7708	5.07	.13 .12 .12	.12
2.09 2.09 2.09	.8965	7.25	15400 15575 14225	15067	17038	11.56	.12 .13 .12	.12
2.60 2.60 2.60	1.726	13.95	27850 28550 28700	28367	32783	13.47	.14 .16 .15	.15
3.11 3.11 3.11	2.954	23.88	48475 46250 45550	46758	56118	16.67	.18 .19 .20	.19

Results of Brinell Hardness Tests

The brinell hardness of the surface of the bars is given in Table 11 and is also shown graphically in Chart 1. Chart 2 shows the results of the brinell hardness tests on the transverse sections of the bars.

Charts

Due to the rather complicated method which had to be followed in presenting the results graphically it is felt that a few words of explanation might not be amiss.

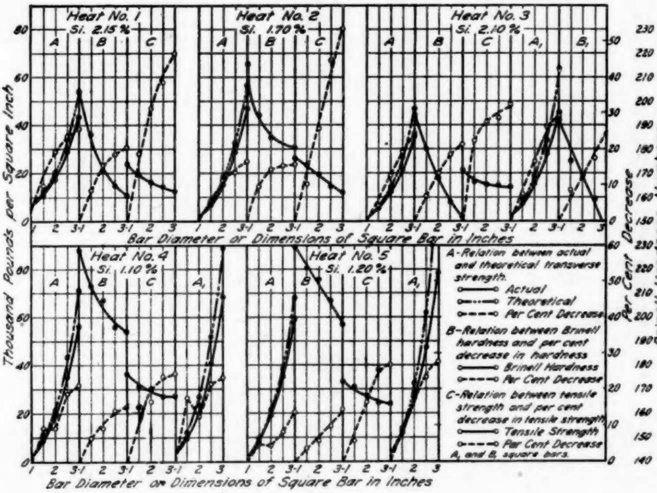

CHART 1—CHART SHOWING RESULTS OF ALL TRANSVERSE, TENSILE, AND SURFACE BRINELL TESTS

Chart 1: In Chart 1 the results of all of the transverse tests, the tensile tests, and the brinell hardness tests on the surfaces of the bars are given. As can readily be seen each heat is separated from the following one by a double set of vertical lines. Between each portion of the graph for a single heat, a vertical line has been used. All of the points are plotted from the averages of the values given in the tables.

In the sections of the graphs marked "A" the relation between the actual transverse strength, the theoretical transverse strength, and the per cent decrease in transverse strength with thickness, is shown. The figures along the bottom 1, 2, and 3 refer to the diameter of the bars tested. The sections marked "A_1" are the results of tests on square bars and the figures 1, 2, and 3 refer to the length of the sides of the square.

Table 4

TRANSVERSE TESTS ON ROUND BARS—HEAT No. 3

Diameter in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.06			2000				.13	
1.06	.1170	1	1850	1917	....	0	.10	.11
1.06			1900				.10	
1.57			4800				.08*	
1.57	.3800	3.25	6150	5975	6230	4.09	.12	.11
1.57			5800				.10	
2.06			12250				.10	
2.06	.8584	7.34	12050	12267	14070	12.81	.11	.10
2.06			12500				.10	
2.55			21150				.10	
2.55	1.628	13.91	21800	21450	26665	19.55	.11	.11
2.55			21400				.11	
3.08			37150				.13	
3.08	2.870	24.53	35150	35517	47024	24.47	.14	.13
3.08			34250				.13	

*Flaw.

Table 5

TRANSVERSE TESTS ON SQUARE BARS—HEAT No. 3

Dimensions in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.03x1.03			2450				.09	
1.03x1.03	.1821	1	2450	2450	....	0	.09	.09
1.55x1.55			8000				.06	
1.55x1.55	.6206	3.41	7450	7725	8355	7.54	.07	.06
1.55x1.55			6800				.09*	
2.03x2.03			15750				.09	
2.03x2.03	1.394	7.66	15150	15667	18767	16.51	.08	.09
2.03x2.03			16100				.09	
2.55x2.55			27500				.10	
2.55x2.55	2.764	15.18	26750	27450	37191	26.19	.09	.09
2.55x2.55			28100				.09	
3.05x3.05			43150				.11	
3.05x3.05	4.729	25.96	44500	45067	63602	29.14	.12	.12
3.05x3.05			47550				.13	

*Flaw.

In the section marked "B" the brinell hardness of the surface of the bars is shown plotted against the per cent decrease in surface hardness, the hardness of the one inch bar being taken as the standard.

In the section marked "C" the tensile strength of the core of the bars is shown plotted against the per cent decrease in tensile strength, the one inch bar again being taken as the standard.

Table 6

TRANSVERSE TESTS ON ROUND BARS—HEAT No. 4

Diameter in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.082			3050				.17	
1.093	.1244	1	2600	3050	....	0	.14*	.17
1.11			2650				.14*	
1.602			7225				.11*	
1.593	.4022	3.23	9375	8937	9851	9.27	.13	.12
1.598			8500				.12	
2.06			20300				.13	
2.07	.8710	7.00	19600	19400	21350	9.13	.15	.14
2.07			18300				.14	
2.62			34900				.09	
2.62	1.766	14.20	36550	35183	43310	18.76	.12	.13
2.62			34100				.17	
3.09			53900				.21	
3.09	2.897	23.29	59500	56067	71035	21.07	.21	.20
3.08			54800				.19	

*Flaw.

Table 7

TRANSVERSE TESTS ON SQUARE BARS—HEAT No. 4

Dimensions in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.02x1.02			3150				.12	
1.03x1.03	.1769	1	3700	3367	....	0	.13	.12
1.02x1.02			3250				.10	
1.55x1.55			10000				.11	
1.55x1.55	.6206	3.508	9500	9750	11811	17.45	.11	.11
1.55x1.55			9150				.10*	
2.03x2.03			23300				.11	
2.02x2.02	1.394	7.88	22400	23332	26532	12.06	.12	.13
2.03x2.03			24300				.15	
2.55x2.55			38000				.19	
2.54x2.54	2.731	15.43	41000	40867	51953	21.34	.15	.16
2.54x2.54			43600				.14	
3.04x3.04			63200				.18	
3.03x3.03	4.682	26.46	70600	68567	89091	23.03	.14	.17
3.05x3.05			71900				.19	

*Flaw.

Chart 2: Chart 2 shows the results of the brinell hardness tests on the transverse sections of the bars from the five heats. The diameter of each size bar has been plotted along the vertical axis. The figures above and below the center line show the distance of the brinell depression from the center of the bar. The heats have been designated as A, B, C, D and E, corresponding to Heats Nos. 1, 2, 3, 4 and 5.

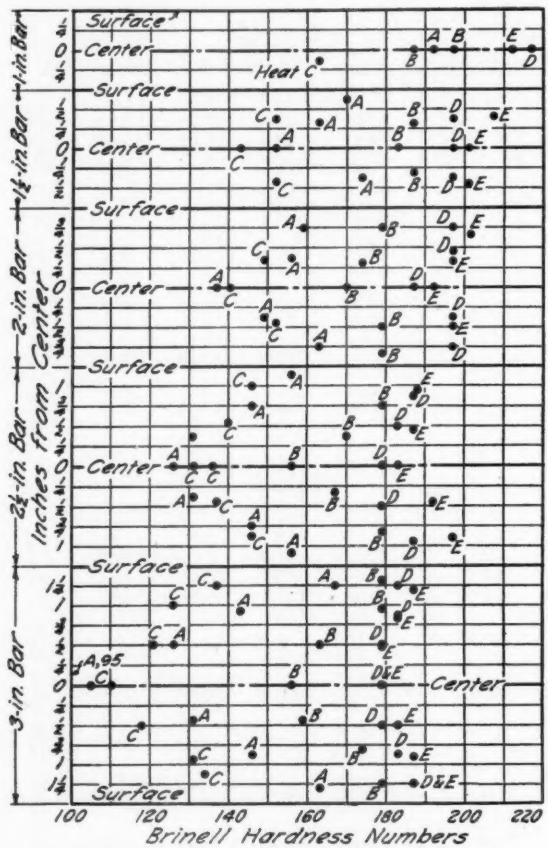

CHART 2—RESULTS OF BRINELL HARDNESS TESTS ON TRANSVERSE SECTIONS

The method of reading this chart can best be illustrated with an example. Suppose we desire to examine the 1½ inch bar of Heat No. 3. By looking at the 1½ inch block we can see three dots marked "C." The dot on the center line marks the hardness at the center of the bar. The other two dots show the hardness at points about ⅜ of an inch from the center.

Table 8

TRANSVERSE TESTS ON ROUND BARS—HEAT No. 5

Diameter in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.07 1.07 1.07	.1203	1	2850 2800 2750	2800	....	0	.11 .14 .14	.13
1.60 1.60 1.60	.4022	3.34	8650 8800 9200	8883	9352	5.01	.15 .12 .12	.13
2.08 2.08 2.08	.8838	7.35	20400 19300 19450	19717	20580	4.19	.13 .12 .11	.12
2.58 2.55 2.56	1.647	13.69	38000 35550 32200	35250	38332	8.03	.16 .18 .17	.17
3.10 3.11 3.11	2.953	24.55	56900 61500 59600	59334	68740	13.68	.17 .20 .16	.18

Table 9

TRANSVERSE TESTS ON SQUARE BARS—HEAT No. 5

Dimensions in Inches	Section Modulus	Factor	Actual Transverse Pounds	Average Transverse Pounds	Theoretical Transverse Pounds	Per Cent Decrease Transverse Strength	Deflection in Inches	Average Deflection in Inches
1.02x1.02 1.02x1.02 1.02x1.02	.1769	1	4200 3800 3600	4000	....	0	.15 .14 .12*	.14
1.53x1.53 1.53x1.53 1.53x1.53	.5969	3.37	12600 10700 12200	12400	13480	8.01	.15 .12* .10	.12
2.05x2.05 2.05x2.05 2.05x2.05	1.436	8.12	22700 24800 28300	26550	32480	18.26	.11* .13 .13	.12
2.54x2.54 2.54x2.54 2.54x2.54	2.731	15.44	51400 43100 47600	47637	61760	23.30	.14 .16 .15	.15
3.08x3.08 3.08x3.08 3.08x3.08	4.869	27.52	76600 77600 85400	79867	110080	27.44	.17 .18 .16	17

*Flaw.

Table 10

TENSILE TESTS ON ROUND BARS

Original Diameter of Bar in Inches	Diameter in Inches	Area in Square Inches	Load Pounds	Tensile Strength Pounds per Square Inches	Per Cent Decrease in Tensile Strength	Remarks
1	.875	.6014	14300	23780	0	Heat No. 1
1½	.875	.6014	11600	19290	18.88	Heat No. 1
2	.874	.6000	9800	16330	31.33	Heat No. 1
2½	.869	.5931	8650	14580	38.70	Heat No. 1
3	.872	.5972	7550	12640	46.84	Heat No. 1
1	.875	.6014	15600	25940	0	Heat No. 2
1½	.875	.6014	13950	23200	10.57	Heat No. 2
2	.875	.6014	11550	19200	26.00	Heat No. 2
2½	.872	.5972	8450	14150	45.45	Heat No. 2
3	.874	.6000	7200	12000	53.74	Heat No. 2
1	.874	.6000	12750	21250	0	Heat No. 3
1½	.874	.6000	9900	16500	22.30	Heat No. 3
2	.874	.6000	9200	15330	27.85	Heat No. 3
2½	.875	.6014	9100	15130	28.80	Heat No. 3
3	.876	.6027	8600	14270	32.84	Heat No. 3
1	.875	.6014	21800	36250	0	Heat No. 4
1½	.874	.6000	18600	31000	14.48	Heat No. 4
2	.875	.6014	18200	30260	16.52	Heat No. 4
2½	.860	.5809	16100	27710	23.56	Heat No. 4
3	.881	.6096	16750	27480	24.19	Heat No. 4
1	.874	.6000	19700	32830	0	Heat No. 5
1½	.875	.6014	18600	30930	5.79	Heat No. 5
2	.875	.6014	16450	27350	16.69	Heat No. 5
2½	.875	.6014	14750	24520	25.31	Heat No. 5
3	.875	.6014	14500	24110	26.56	Heat No. 5

Table 11

BRINELL HARDNESS OF THE SURFACE OF THE BARS

Diameter of Bars in Inches	Average Brinell Hardness No.	Per Cent Decrease in Hardness	Remarks
1	203.0	0	Heat No. 1
1½	186.2	8.27	Heat No. 1
2	171.0	15.76	Heat No. 1
2½	164.6	18.91	Heat No. 1
3	161.0	20.69	Heat No. 1
1	215.2	0	Heat No. 2
1½	194.3	9.72	Heat No. 2
2	184.7	14.17	Heat No. 2
2½	182.1	15.40	Heat No. 2
3	181.2	15.80	Heat No. 2
1	194.0	0	Heat No. 3
1½	180.0	7.22	Heat No. 3
2	168.0	13.40	Heat No. 3.
2½	158.0	18.56	Heat No. 3
3	152.0	21.65	Heat No. 3
1	192.0	0	Heat No. 3B
1½	175.0	8.85	Heat No. 3B
2	168.1	12.50	Heat No. 3B
2½	158.6	17.40	Heat No. 3B
3	146.0	23.96	Heat No. 3B
1	228.0	0	Heat No. 4
1½	213.0	6.58	Heat No. 4
2	207.0	9.21	Heat No. 4
2½	196.0	14.03	Heat No. 4
3	194.0	14.91	Heat No. 4
1	230.2	0	Heat No. 5
1½	221.6	3.73	Heat No. 5
2	216.7	5.86	Heat No. 5
2½	207.8	9.73	Heat No. 5
3	196.6	14.59	Heat No. 5

Values are averages of (10 or more) readings.
3B—Square bars.

Photomicrographs

The microstructure of the bars in Heat No. 1 is shown in Figs. 3 to 7. This was a heat of what we have termed common iron and had 2.15 per cent silicon.

The second set of photomicrographs, Figs. 8 to 12, shows the microstructure of Heat No. 4, a semi-steel with 25 per cent steel.

These photographs were taken mainly to show the size of the graphite plates and to give some idea of the composition of the matrix.

Discussion

Tests: In discussing this series of tests, it appears logical to separate the results into three divisions: The first, Heats Nos. 1 and 3, which are common iron with practically the same chemical analysis; the second, Heat No. 2, a semi-steel with 15 per cent steel and having a silicon content of 1.70 per cent; the third, Heats Nos. 4 and 5, semi-steels with 25 per cent steel and with a similar composition.

Division No. 1: Comparing the transverse tests of these two heats there is found very close agreement in the per cent decrease in strength. In Heat No. 1 the per cent decrease in strength on the 3 inch bar is 22.18 per cent, while in Heat No. 3 it is 24.47 per cent. For iron of this composition the strength apparently falls off at the rate of about 6 per cent for each increase in thickness of ½ inch; or 12 per cent per inch increase in thickness above an original thickness of one inch.

The per cent decrease in brinell hardness of the surface of the bars in these two heats coincides within practical limits. It is to be noted that the decrease in surface hardness is very close to the per cent decrease in transverse strength. It appears that the curve showing per cent decrease in transverse strength and the per cent decrease in surface hardness coincide.

In the tensile strength determinations Heat No. 1 showed an average of about 11 per cent decrease in strength of core with each ½ inch increase of thickness greater than one inch. This value is somewhat higher than the value found in Heat No. 3 where about 8 per cent appears as the per cent decrease in

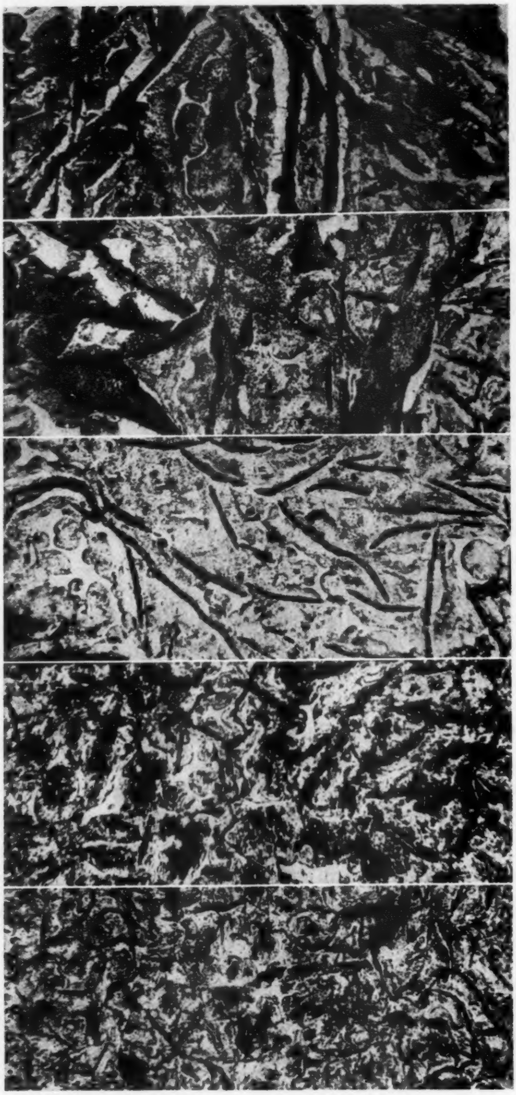

FIG. 3
1 INCH BAR

FIG. 4
1½ INCH BAR

FIG. 5
2 INCH BAR

FIG. 6
2½ INCH BAR

FIG. 7
3 INCH BAR

ALL BARS 2.15 PER CENT SILICON—MAGNIFIED 100X—ETCHED

FIG. 8
1 INCH BAR

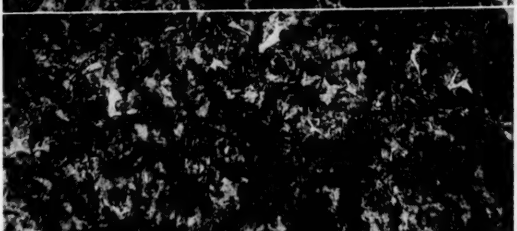

FIG. 9
1½ INCH BAR

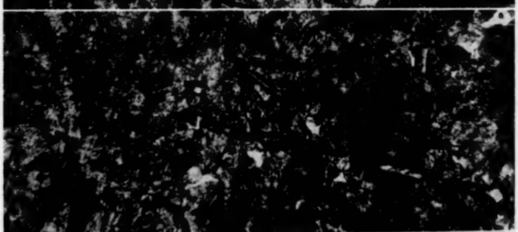

FIG. 10
2 INCH BAR

FIG. 11
2½ INCH BAR

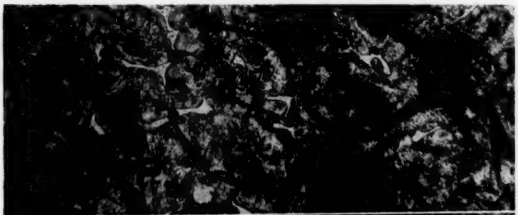

FIG. 12
3 INCH BAR

ALL BARS 1.10 PER CENT SILICON—MAGNIFIED 100X—ETCHED

tensile strength for each ½ inch greater than one inch in thickness. The average falls around 9½ per cent for each ½ inch increase; or about 19 per cent decrease for each 1 inch increase.

In Heat No. 3 square bars were studied in addition to the round ones. On comparing the curves of the square bars with those of the round bars it will be seen that in both cases, brinell and transverse, the per cent decrease in the square bars is greater.

Upon examining the results of the transverse tests on the square bars, it is found that the per cent decrease is about 7½ per cent per half inch increase in thickness; or about 15 per cent per inch. This is 1½ per cent greater than found for the round bars per half inch increase or 3 per cent greater per inch.

The per cent decrease in surface hardness is slightly greater for the square bars; but the difference is not great.

While individual values vary, it can be seen that the results obtained in these two tests compare very favorably.

Division No. 2: Division No. 2 is a heat of 1.70 per cent silicon content, made with 15 per cent of steel. In this case the per cent decrease in transverse strength on the 3 inch bar is 16.67 per cent. This is a decrease of about 4 per cent per ½ inch of thickness above the standard 1 inch; or 8 per cent per inch.

The per cent decrease in surface hardness again follows the per cent decrease in transverse strength.

The per cent decrease in tensile strength appears to be in the neighborhood of 12½ per cent per ½ inch, or 25 per cent per inch; but this figure seems rather high. However, since only one tensile test was made on each size bar the results have not the same significance as those obtained from averages. For this reason, it is felt that if several tests were made with this metal the figures would be much less since the steel in the mixture should improve the metal and give it greater strength than found in the ordinary run of iron.

Division No. 3: Heats Nos. 4 and 5 have been designated as division No. 3. Both of these were made with 25 per cent steel so that they are really what is commonly called semi-steel rather than an ordinary heat of low silicon cast iron. These two heats had practically the same chemical analysis with slight

variations from element to element. For comparative purposes, however, they have been considered the same.

In transverse strength Heat No. 4 shows a decrease of 5.25 per cent per ½ inch increase in thickness or 10.5 per cent per inch. Heat No. 5 shows about 3.3 per cent per ½ inch or 6.6 per cent per inch.

The surface hardness in both heats decreases at the same rate with the increase in thickness. In Heat No. 5 the per cent decrease is fairly close to the per cent decrease in transverse strength.

The core of the bars in both heats showed about the same per cent decrease in tensile strength; 6.3 per cent per ½ inch; or about 12.6 per cent per inch.

The square bars of the heats were only tested transversely. These gave an average decrease in strength of 6.3 per cent per ½ inch; or 12.6 per cent per inch. Here again the square bars show a greater percentage decrease than the round ones.

In both of the heats the per cent decrease in transverse strength on the 2 inch bar proved to be less than that found for the 1½ inch bar. This produced a jog in the curves at these points. Whether this is some property of the mixture or whether it is from some outside cause has not as yet been determined.

Brinell on Transverse Sections: It was thought that some relation could be found tying up the change in hardness from the center to the surface of a bar with either the tensile strength or the transverse strength.

No apparent relationship could be detected between the hardness of the transverse sections and the tensile strength. However, if all of the hardness values, found for a 3 inch bar in any one heat, are averaged, and the result compared with the value for the 1 inch bar, a relation to the transverse strength is found.

In Heat No. 1 the average of the values for the 3 inch bar is 139, against 187 of the 1 inch bar. The difference is 25.66 per cent, which compares with a decrease in transverse strength of 22.18 per cent.

The following values show the results of the other heats:

In Heat No. 2, 14.21 per cent brinell against 16.80 per cent;

in Heat No. 3, 23.62 per cent brinell against 24.47 per cent transverse; in Heat No. 4, 16.13 per cent brinell against 21.07 per cent transverse; and in Heat No. 5, 13.44 per cent brinell against 13.68 per cent transverse.

Discussion of Photomicrographs: A study of the photomicrographs, Figs. 3 to 12, does not show anything very startling. In both heats it can be seen that the graphite flakes gradually increase in length as the thickness of the bars increases. The matrix of the 1 inch bar in both cases is composed of pearlite and sorbite, with a few small areas of ferrite and some steadite in the common iron. As the thickness of the bars increases, the graphite areas become larger with more free ferrite showing until in the 3 inch bar there is a fair amount of free ferrite. This condition is most pronounced in the common iron. The semi-steel, while showing the formation of longer graphite flakes, does not show such a marked increase in the amount of free ferrite.

As an aid in understanding the reason for the decrease in strength with increasing thickness, the pictures prove valuable. It can be seen at a glance that the core of the 3 inch bar is weaker than that of the 1 inch bar, due to the breaking up of the continuity of the matrix by the long graphite flakes. A slower rate of cooling causes a greater separation of the graphite in the larger bars producing the long heavy flakes. This is the reason for the failure of cast iron to follow the formulas as set down for steel beams.

Conclusions

1. In order to determine any factor applicable to the decrease in strength with thickness considerable more research work is necessary.

2. The decrease in surface hardness of a casting is a direct indication of the decrease in strength.

3. The per cent decrease in transverse strength tends to follow the silicon content. High silicon irons show greater decrease in transverse strength than low silicon irons containing steel.

4. Semi-steels show less decrease in strength, transversely in all of the heats, and in tension in the 25 per cent steel heats.

Acknowledgement

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Principles and Chief Applications of Dilatometric Analysis of Materials*

By A. Portevin† and P. Chevenard‡, Paris, France

I. *Thermal Analysis and Physical Analysis. Superiority of Dilatometric Analysis*

Thermal analysis seizes and records the polymorphic transformations of a substance while these reactions are occurring. It determines the temperature, speed and intensity, gives information as to their nature and their character, and permits a reconstitution of the continuous chain of phenomena which connects the initial state and the final state. While micrography indicates only the total result of a treatment, thermal analysis succeeds in elucidating the mechanism of this treatment, information essential for directing tempering or annealing operations: it therefore has a double scientific and practical interest.

The methods of thermal analysis are divided into two groups:

Thermal methods properly so-called (Roberts-Austen's and Dejean's chronograph methods) call upon the calorific properties of the alloys. Their use is very general, for a change of state is always accompanied by a more or less intense and more or less marked thermal phenomenon; they are applicable to solids and liquids.

But their sensitiveness depends in the highest degree upon the rate of heating and cooling; they therefore fail in the study of very low reactions. Furthermore, the quantitative comparison of the phenomena is often delicate, uncertain and sometimes impossible when the speed varies between wide limits. This inconvenience is serious in the study of heat treatment, a study of which one purpose is precisely the elucidation of the role of the rate of heating and cooling.

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Physical methods, based on the study of expansion, electrical properties, magnetization, etc., are free from this trouble. They therefore permit the study of very slow or very rapid reactions and a quantitative description of the transformations.

A—*Principle of the Methods of Physical Analysis-Advantages of the Dilatometric Method*

The manifestations observed during the heating and cooling of a sample are caused by; 1st, the *specific transformations* of the constituents—allotropic transformations with change of phase, anomalous transformations without change of phase and decomposition of phases out of equilibrium; 2nd, the *reactions between phases.* A close study of these phenomena therefore permits:

Following the mechanism of a reaction in all its details and estimating its importance according to the intensity of the phenomena which indicates it.

Controlling, afterward, the results of a reaction, for from the magnitude of the properties of the constituent phases and the intensity of their specific anomalies, the proportion of each one of them can be estimated approximately.

Among the methods for the physical analysis of solids, that which is based on observation of the phenomena of *linear expansion* appears to be the most sensible, simplest and most precise.

In fact, changes of state of substances always affect the dimensions of the sample. The magnitude of the phenomenon is always considerable and consequently very easy to measure in a great number of industrial products: iron alloys, bronzes, silica brick, etc.

But even in the case where the dilatometric peculiarity is very weak, as in duraluminiums, a minute analysis can always be made, for extremely sensitive processes for measuring small changes of length are now available.

Finally, the results of dilatometric analysis are easy to interpret. The expansion of an aggregate never deviates much from that which can be foreseen from the law of mixtures; any specific anomaly of an element of the aggregate is therefore shown by an irregularity of the expansion curve, even if this element is very small in quantity.

The dilatometric method presents the advantage over the electric and magnetic methods of less sensitiveness to secondary actions: impurities, thermal history, etc. For example, a trace of impurity can increase the resistance of a metal noticeably, while the change of expansibility is always of the same order of magnitude as the proportion of the foreign element. Therefore, parasitic phenomena can not mask essential facts; but thanks to the sensitiveness of the dilatometric method, one can make a minute study of the secondary manifestations and so progress, step by step, towards knowledge of the real phenomena.

On the other hand, this method can be applied only to solids; it ceases to be useful at temperatures at which viscous deformations become preponderant. Cubic expansion must then be called upon, the measurement of which is unfortunately less precise and much less easy than that of linear expansion.

We shall explain succinctly the technique of dilatometric analysis, as it is worked out at the laboratory of the Imphy steel works of the Société de Commentry-Fourchambault at Decazeville. Then we will review some of the results made possible by it.

B—*Technique of Dilatometric Analysis*

In the differential recording dilatometers invented, built and used at the Imphy laboratory, the diagrams are drawn photographically or by a mechanical process. As these two models of the apparatus have already been described in several technical publications[1], we will merely review the principle, the qualities and conditions of use.

The dilatometer refers the expansion of the sample being studied, E_1 (Fig. 1) to that of a suitably chosen standard E_2 brought to the same temperature. These expansions are transmitted by an invar tripod, the three points of which, p_1, p_2, p_3, form a right angle triangle. The point of the right angle p_2 receives the expansion of the standard and p_1 that of the sample; p_3 rests on a fixed surface of the apparatus. A socket O and a groove r prevent any displacement of the tripod in its plane. When

[1] P. Chevenard. Revue de Mètallurgie, 1917, v. 14, p. 610, and Bulletin de la Société des Ingénieurs Civils, September, 1923, for the photographic dilatometer; Revue de Métallurgie, 1926, v. 23, p. 92, for the mechanical dilatometer.

the test pieces expand, the tripod is impelled with a motion equivalent to two rotations around the rectangular axes OX, OY.

1. In the *photographic dilatometer,* the tripod carries a concave mirror M (Fig. 1) that causes the luminous pencil emanating from a very small source to converge on a photographic plate. The double motion of the tripod causes the image of the luminous point to describe a curve; every point of this curve has, as ordinate, the difference between the expansions of the test piece and the standard, and as abscissa the expansion of the standard, which registers the common temperature of the two test pieces.

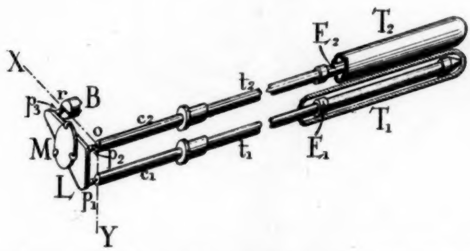

FIG. 1—DIAGRAM OF THE DIFFERENTIAL, PHOTOGRAPHIC RECORDING DILATOMETER

2. In the *mechanical dilatometer,* the mirror is replaced by a long pointer (Fig. 2) fixed perpendicularly to the tripod; the pen placed at the end of this pointer draws the curve of differential expansion on a sphere, the center of which is the fixed point p_3. To register a plane curve, it suffices to place the sheet of paper on a table to which a reciprocating motion is imparted, perpendicular to its plane and along the mean direction of the pointer, in such a way as to obtain an intermittent contact of the pen and the paper: the curve is traced by points.

In order to obtain sufficient sensitiveness in spite of the relatively slight length of the pointer (20 cm.), the expansions of the test pieces are magnified by means of two levers of the second class L_1, L_2 (Fig. 2) before transmission to the tripod Tr.

The very light pointer, of aluminium, carries at its end a pen P (Fig. 3) fastened on a tube sliding on the pointer. A spring

r tends to push back the tube and assures contact when the paper-carrying table advances to meet the pen; but the distance is limited by a pin g.

This table is displaced reciprocally by the action of an expanding-wire motor (Fig. 4); the wire F is heated and expanded by the passage of an electric current, the periodic breaking of which is caused by a mercury interrupter I, controlled by the expansion of the wire itself. By acting upon the milled knob of the stretcher

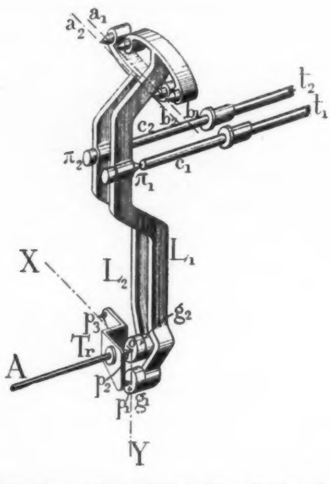

FIG. 2—DIAGRAM OF THE AMPLIFYING ARRANGEMENT OF THE DIFFERENTIAL, MECHANICAL, RECORDING DILATOMETER

B and on the screw V, the working temperatures of the wire are changed and, consequently, the frequency of the oscillations, the average period of which is about 4 seconds.

The successive points are close enough together to give the illusion of a continuous line, except in the case of rapid cooling or sudden transformations; the spacing of the points then permits the speed with which the curve is described to be appreciated.

When it is desired to study the expansion of substances that it is impossible to shape into rods (quartz, silica brick, coal, min-

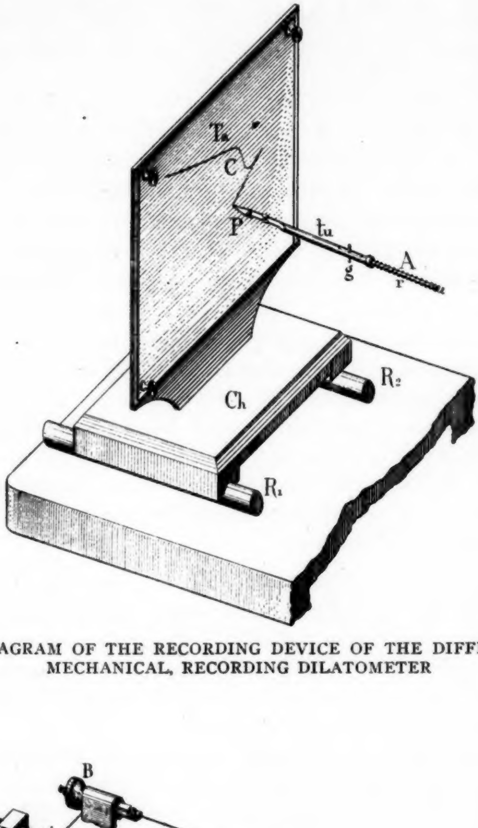

FIG. 3—DIAGRAM OF THE RECORDING DEVICE OF THE DIFFERENTIAL, MECHANICAL, RECORDING DILATOMETER

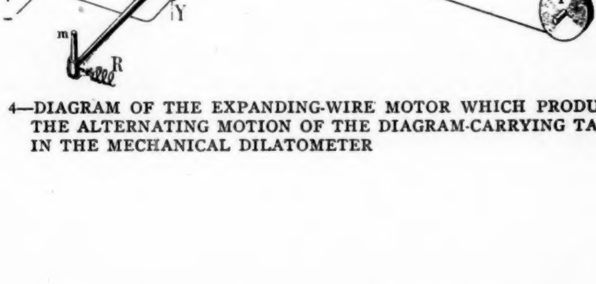

FIG. 4—DIAGRAM OF THE EXPANDING-WIRE MOTOR WHICH PRODUCES THE ALTERNATING MOTION OF THE DIAGRAM-CARRYING TABLE IN THE MECHANICAL DILATOMETER

erals, rocks, etc.), the test piece is constructed of several fragments, roughly dressed on the grindstone and placed end to end on a rimmed platform of silica glass joined to the end of the dilatometer tubes. The heating must be slow, for the test-piece and the pyros standard in such a case have rather different calorific capacities; a good conducting muffle of nickeled copper placed in the furnace assists the equalization of the temperature.

The optical recording dilatometer is especially an apparatus for research and scientific study, for it reveals with great precision and great delicacy the outline of the slightest dilatometric irregularities.

The mechanical recording dilatometer has the great advantage of furnishing a curve that is constantly visible while being traced; the phenomena can therefore be followed and the progress of the operation stopped or modified when desired. It is therefore suitable for a rapid and immediate study of an unknown material. Robust, insensitive to vibrations, it can be put in any hands, and it is consequently adapted to the work of industrial and educational laboratories.

Standard. In order to play the double rôle of sample for comparison and of pyrometric indicator, the standard should be practically unoxidizable and rigid within the temperature range where it is used; its thermal properties should be regular, exactly reversible, and its expansion not very different from the average of that of the substance being studied.

In some cases, iron, copper or aluminum are suitable; most often a nickel-chromium-tungsten alloy, mixed with iron and manganese, called pyros, is used, which possesses to a high degree the qualities mentioned.

The field of application of the apparatus equipped with pyros extends from the lowest temperatures to 1100 degrees Cent. and even to 1200 degrees Cent.

Properties of differential dilatometers. The standard chosen, having an average expansion not very different from that of the sample, a high magnification in the direction of the ordinates can be allowed without giving inconvenient dimensions to the diagrams: the differential dilatometer is *sensitive.*

Thanks to the use of the expansion pyrometer, it is also robust, faithful, not liable to derangement and entirely ***indifferent*** to vibrations. The curves are entirely devoid of accidental sinuosities. It is therefore possible by a single graphic elaboration shown on Fig. 5, to obtain the derived curve Γ which shows clearly the least irregularities of the registered curve C.

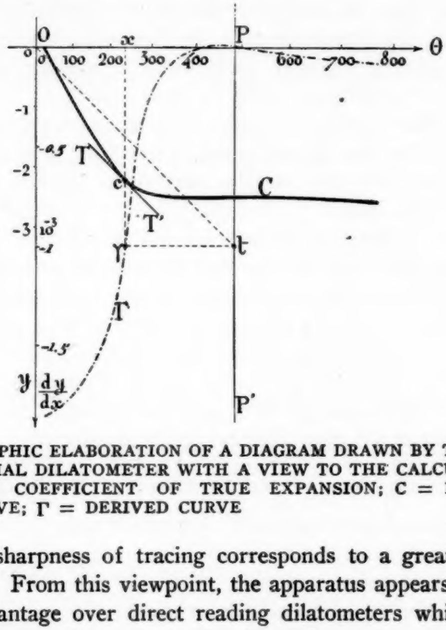

FIG. 5—GRAPHIC ELABORATION OF A DIAGRAM DRAWN BY THE DIFFERENTIAL DILATOMETER WITH A VIEW TO THE CALCULATION OF THE COEFFICIENT OF TRUE EXPANSION; C = REGISTERED CURVE; Γ = DERIVED CURVE

This sharpness of tracing corresponds to a great ***power of definition.*** From this viewpoint, the apparatus appears to present a real advantage over direct reading dilatometers which force a construction of the curve, point by point, and over recording devices requiring a galvanometer always more or less affected by vibrations.

Uniformity of temperature. The operation of the dilatometer assumes that the two samples, at every instant and in all their points, have the same temperature. In what measures is this condition realized? Detailed control tests have been undertaken for this purpose.

To insure this thermal uniformity, identical masses are given to the sample and the standard; their calorific capacities are not very different on the average; the apparatus is exactly centered in the electric furnace and the latter is equipped with a good conducting muffle of nickeled copper. Finally the rate of heating or cooling is habitually below 300 degrees Cent. an hour. These precautions insure equality of temperatures almost *within 2 degrees,* except when the sample is the seat of a thermal phenomenon by the action of a transformation. In this case a systematic variation of temperature appears, from which a parasitic hook results on the curve, examples of which we shall show.

To eliminate them, it is sufficient to place the standard within the sample[2]. In this mounting the pyrometric pointer, very light in comparison with the sample, participates without lag in its changes of temperature.

But in reading a diagram, true irregularities are easily distinguished from parasitic hooks; these latter are always localized in a short interval of temperature; their direction can be foreseen and their amplitude varies in inverse ratio to the speed of heating or cooling; so, as the tubular sample is more difficult to prepare than a bar, especially in the case of white cast iron, we use chiefly the usual mounting with juxtaposed samples, remembering to be prudent in the interpretation of the diagrams.

C—Calculation of the Coefficient of Expansion

The differential dilatometer serves not only for the thermal analysis of materials, but it also permits the measurement of their expansibility at any temperature below 1100 to 1200 degrees Cent. This estimation is based on the graphical determination of the derivative at all points of the curve registered, by the method of tangents.

Designate by X and Y the co-ordinates at the point *C* of the the recorded curve C (Fig. 5) and let pp′ be parallel to the axis of the ordinates, the abscissa OP of which is taken as unity. From the origin O, a parallel is drawn at TT′: this straight line Ot cuts, on PP′, a segment Pt equal to the derivative $\frac{d\,y}{d\,x}$ at the point *C*.

[2] A. Portevin and P. Chevenard. "Remarques et observations concernant les phénomènes de trempe des aciers," Revue de Métallurgie, 1921, v. 18, p. 428.

Point γ, obtained by referring point t to the ordinate of point c, belongs to the derived curve Γ.

This operation admits of sufficiently great precision, for the registered curves are clear and fine; furthermore, the errors committed in estimating the directions of the different tangents are totally independent. It is thus sufficient to multiply the γ points to eliminate, by compensation, the accidental errors in the outline of the derived average curve.

Calculations of the true coefficient. By definition, the coefficient of true expansion $\propto$ of a substance at a temperature Θ has for its expression: $\propto = \frac{1}{Lo} \times \frac{\delta L\theta}{\delta\theta} = \frac{\delta\Delta}{\delta\theta}$

Lo and $L\theta$ designate the length of the sample at O°, and at $\theta°$, and Δ the ratio: $\Delta = \frac{L\theta - Lo}{Lo}$

Let K_1 and K_2 be the coefficients of magnification of the optical lever along the axes OX and OY. The abscissa χ and the ordinate γ have for their expression:

$$\chi = K_1 Lo\ (\Delta \text{ standard} - \Delta \text{ silica})\ ;$$
$$\gamma = K_2 Lo\ (\Delta \text{ sample} - \Delta \text{ standard})$$

By derivation we obtain: $\propto$ sample $- \propto$ standard $=$

$$\frac{1}{K_2 Lo} \cdot \frac{\delta\gamma}{\delta\theta} = \frac{1}{K_2 Lo} \cdot \frac{\delta\gamma}{\delta x} \cdot \frac{\delta x}{\delta\theta}$$

Now: $\frac{\delta x}{\delta\theta} = K_1 Lo\ (\propto \text{ standard} - \propto \text{ silica})$

From which the final expression:

$$\propto \text{ sample} = \propto \text{ standard} + \frac{K_1}{K_2} \cdot \frac{\delta\gamma}{\delta x} \cdot (\propto \text{ standard} - \propto \text{ silica})$$

Direct calibration by means of Johannson gages make it possible to obtain the coefficients of magnification K_1 and K_2: in the original Imphy apparatus they had the values 140 and 300 respectively. The expansion of silica is now known with precision (Le Chatelier, Holborn, etc.)[3]. The same is true of the expansion of pyros, which has been the object of numerous measurements carried out at the Imphy laboratory.

[3] Between 0° and 1,000° a linear law can be accepted: Δ silica $= 0.54.\ 10^{-6}\ \theta$.

True coefficients, calculated by the method shown, are obtained with sufficiently high accuracy: the error is nearly always less than 0.2×10^{-6}.

D—Expansion of Pyros

Pyros alloy is practically devoid of thermal irregularity: the complex chromium-tungsten-manganese-iron addition lowers to very low temperatures (around -175 degrees Cent.) Curie point of the nickel and, as a consequence, causes the dilatometric anomaly

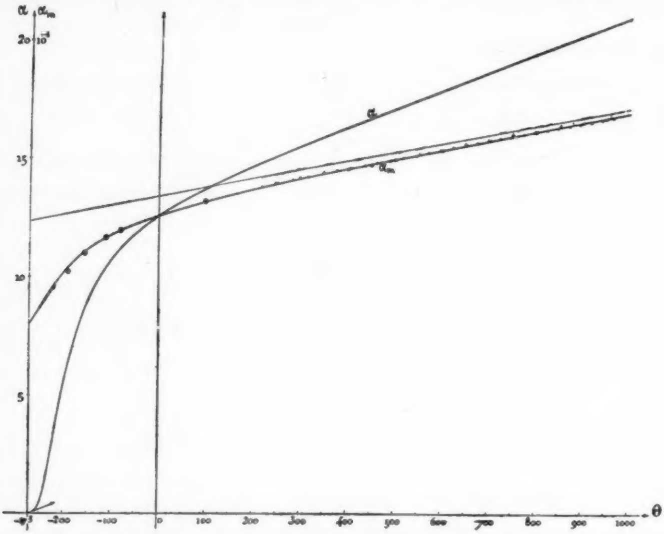

FIG. 6—COEFFICIENT OF EXPANSION OF PYROS ALLOY. αm = AVERAGE COEFFICIENT OF EXPANSION BETWEEN ZERO CENTIGRADE AND TEMPERATURE Θ. α = COEFFICIENT OF TRUE EXPANSION AT THE TEMPERATURE Θ: $\alpha = \frac{1}{L_0} \cdot \frac{\delta L_\theta}{\delta \theta}$

that accompanies the magnetic transformation of this last metal to disappear. On the other hand, the anomaly of nickel-chromium alloys towards 550 degrees, discovered by one of us, is practically suppressed by the combined action of the added elements. A normal law of expansion can therefore be attributed to pyros.

The expansion of normal substances at high temperatures can be expressed exactly enough by a parabolic function of the temperature. This is verified by placing on a diagram, for any centigrade temperature θ, the value of the coefficient of average expansion α_m between 0 and θ; the points obtained are arranged nearly in a straight line. Such is quite the case for the α_m points of pyros beyond 200°; in Figure 6 the points marked ✕▲ and ⊙ correspond to independent groups of very careful tests.

But at very low temperatures the parabolic law is no longer true: the curve of the average coefficient α_m curves inward toward the bottom, below zero centigrade. It is known, in fact, that the true expansion of solid bodies tends toward zero as the temperature approaches the absolute zero.

Modern theories on the constitution of matter permit the thermal variation of the expansion of normal substances to be predicted; they lead to an interpolation formula that groups in a satisfactory manner all the experimental results relative to pyros.

A close analogy of conduct exists between the thermal variation of the true expansion of a normal metal and that of the true specific heat at constant pressure, the magnitude for which the quantum theory predicts the thermal increase. It was therefore logical to test, for the coefficient of true expansion of pyros, a formula of the form:

$$\alpha = A\left[\frac{\left(\frac{C}{T}\right)^2 \; e^{\frac{C}{T}}}{\left(e^{\frac{C}{T}}-1\right)^2} + \frac{\left(\frac{C}{2T}\right)^2 \; e^{\frac{C}{2T}}}{\left(e^{\frac{C}{2T}}-1\right)^2}\right] + 2\,BT$$

admissible except in the immediate neighborhood of the absolute zero. A, B, C are three constant and T the absolute temperature[4].

In order to submit this hypothesis to the check of experiment, the easiest method consists in calculating, from the above formula, the curve of the average coefficient:

$$\alpha_m = \frac{1}{\theta}\int_0^{\theta} \alpha \, . \, \delta\theta$$

and comparing it with the experimental values of α_m. As the diagram of Fig. 6 shows, the agreement is very satisfactory be-

[4] This formula differs but little from that which has been proposed by Nernst and Lindeman to represent the true specific heat of normal substances.

tween -190 degrees, the temperature of liquid air, and + 1000 degrees Cent.

Table 1 groups the results of our measurements, worked out by the method explained, Δ_{0}^{θ} represents the true expansion of pyros between 0° and θ°, and ∝ the true coefficient at θ°.

II—Application of Dilatometric Analysis

A—Dilatometric Characteristics of the Different Types of Transformations

1—Transformation Without Change of Phase of Ferromagnetic Substances

Dilatometric Anomaly of Cementite

Radiographic analyses, especially the experiments of Westgren[5], have finally confirmed the conclusion of Le Chatelier,

TABLE 1

Θ	$10^3 . \Delta^\theta$.	$10^6 . \propto$
—200°	—2.039	5.49
—150°	—1.670	8.90
—100°	—1.175	10.71
— 50°	—0.610	11.80
0°	0	12.57
50°	0.644	13.19
100°	1.319	13.73
150°	2.017	14.22
200°	2.740	14.69
250°	3.485	15.13
300°	4.252	15.56
350°	5.042	15.99
400°	5.851	16.41
450°	6.683	16.82
500°	7.536	17.23
550°	8.405	17.64
600°	9.296	18.04
650°	10.209	18.44
700°	11.143	18.85
750°	12.095	19.25
800°	13.065	19.65
850°	14.056	20.05
900°	15.070	20.44
950°	16.102	20.84
1,000°	17.153	21.24

Grenet and P. Weiss concerning the nature of the reversible transformation of ferromagnetic substances: this transformation takes place without change of phase. One of us has shown[6] that it is always accompanied by an anomaly of expansion consisting in a

[5] A. Westgren. Roentgen spectrographic investigations of iron and steel. Journal of the Iron and Steel Institute, v. 103 (1921), p. 303.

[6] P. Chevenard. Relation entre la dilatation anomale et la variation thermique de l'aimantation descorps ferromagnétiques. Comptes Rendus de l'Académie des Sciences, 1921; v. 172, p. 1655.

progressive and reversible change of the true coefficient in the region of temperature where the magnetism changes rapidly. But the direction and the intensity of the phenomenon vary from one substance to another.

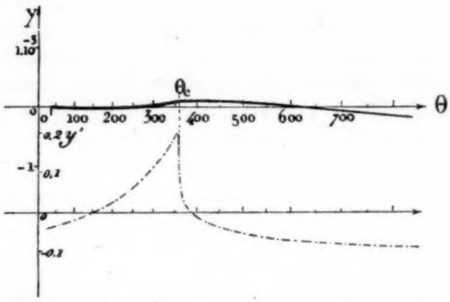

FIG. 7—DIFFERENTIAL DILATOMETRIC CURVE OF PURE NICKEL. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD. THE POINT OF INFLECTION θ_c OF THE DERIVED CURVE (TRACED IN DOTS AND DASHES) COINCIDES WITH THE CURIE THERMO-MAGNETIC POINT

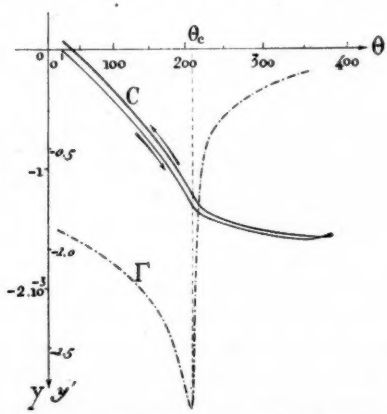

FIG. 8—DIFFERENTIAL DILATOMETRIC CURVE OF CEMENTITE. PHOTOGRAPHIC DILATOMETER. ELECTROLYTIC IRON STANDARD. C — REGISTERED CURVE; Γ — DERIVED CURVE

This, in pure nickel (Fig. 7), the evolution from the ferromagnetic state to the paramagnetic state is effected with expansion, and the normal expansion is found to be accelerated: the anomaly

is *positive*. The termination of the phenomenon is marked by a rapid diminution of the true coefficient: the temperature Θc of the point of injection of the derived curve coincides with the Curie thermomagnetic point.

The magnetic transformation of cementite (Fe_3C) is accompanied by an anomalous condensation that compensates in part the normal thermal expansion: there results an extremely pronounced *negative* anomaly (Fig. 8), which is found again in all aggregates containing cementite in the free state. This anomaly is therefore a sensitive reaction of the carbide Fe_3C.

In order to obtain nearly pure cementite, we separated it from a carbon steel by Arnold's method. A weak hydrochloric acid

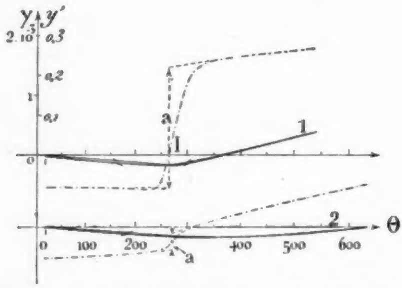

FIG. 9—DILATOMETRIC ANOMALY OF α "COPPER-ALUMINUM" SOLID SOLUTIONS. PHOTOGRAPHIC DILATOMETER. FERRO-NICKEL STANDARD CONTAINING 25 PER CENT Ni. THE REGISTERED CURVES ARE SOLID LINES, THE DERIVED CURVES ARE DRAWN IN DOTS AND DASHES. CURVE 1: 9.16 PER CENT Al ALLOY; CURVE 2: 3.80 PER CENT Al ALLOY

solution is electrolyzed, using for cathode a lead plate and for anode a sheet of very pure steel containing 1 per cent C and 0.25 per cent Mn. This steel had been annealed for a long time in order to obtain relatively large grains of cementite by coalescence. Only the ferrite is attacked by the electrolyte, and the insoluble cementite precipitates in the form of a black powder. This powder, triturated with some thousandths of sodium silicate and then compressed in a mold that can be taken apart, furnished a rod solid enough for the expansion test.

As in the case of pure nickel, the temperature Θc of the derived curve, coincides with the Curie point determined by thermal

methods: 210 degrees, according to Wologdine, Dejean, Honda, etc.

2—Transformation Without Change of Phase in Solid Solutions

In ferromagnetic solid solutions, as in pure metals and definite compounds, the thermal disappearance of strong magnetism is accompanied by a positive or negative anomaly of expansion. Thus the reversible ferro-nickels present an extremely pronounced

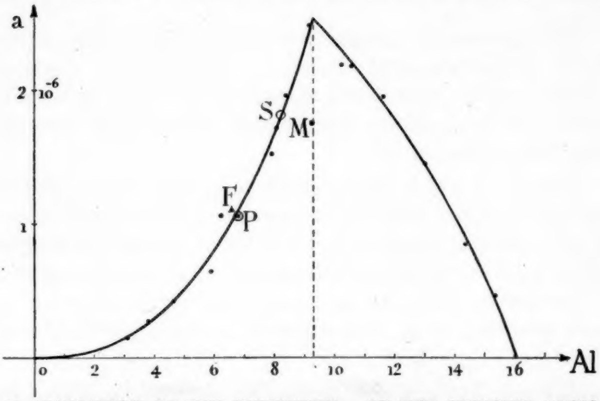

FIG. 10—VARIATION OF THE INTENSITY α OF THE SPECIFIC ANOMALY OF L (CU-A1) SOLID SOLUTIONS WITH THE ALUMINIUM CONTENT. THE DOTS RELATE TO ALLOYS MADE OF ELECTROLYTIC COPPER AND ALUMINUM CONTAINING 99.3 PER CENT Al. POINT P RELATES TO AN ALLOY PREPARED FROM AN ALUMINIUM OF EXCEPTIONAL PURITY, 99.7 PER CENT Al. THE ALLOYS TO WHICH POINTS S, F, M REFER CONTAINED, RESPECTIVELY, 1 PER CENT OF SILICON, IRON OR MANGANESE

negative anomaly: for the alloy containing 35.5 per cent Ni, the anomaly acquires such an intensity that expansion is practically annulled over a large range of temperature in the neighborhood of the atmosphere (invar alloy).

But numerous paramagnetic or diamagnetic solid solutions themselves show a quasi-reversible transformation with anomaly of expansion: copper-zinc, copper-aluminum, nickel-copper, nickel-chromium (these latter in the range of temperature above the Curie point) etc. The phenomenon is progressive and does not appear to correspond to a change of phase.

Thus the differential dilatometric curves of the solid solutions (Cu-Al) α (Fig. 9) show, between 250 and 300 degrees, a change of direction to which a rapid increase of the true expansibility corresponds. The average temperature of the phenomenon, marked by the position of the point of inflection I of the derived curve is obviously independent of the aluminum content. But the intensity characterized by the increase δ of the expansibility, increases in an accelerated fashion with the aluminum content (Fig. 10).

This phenomenon presents a certain analogy to the reversible anomaly of ferromagnetic substances. But while the Curie point of ferromagnetic alloys almost always varies greatly with the composition, the temperature characteristic of the new anomaly is nearly independent of this.

Curve 2 of Fig. 9 requires another remark: the derived curve shows an irregularity that the appearance of the original curve did not lead to be suspected. This result shows the great sensitiveness realized by drawing the derived curves and proves the superiority of a continuous recording apparatus, drawing the diagrams sufficiently clear and strong to be submitted to this graphic elaboration.

3—Allotropic Transformations or Transformations With Change of Phase

Pure iron furnishes a well characterized example of transformation with change of phase. γ iron, stable at a high temperature, has a crystalline lattice[7] (face-centered cubes) and physical properties absolutely distinct from the lattice (cube-centered) and properties of α iron stable in the cold: the allotropic transformation $\alpha \rightarrow \gamma$ is shown by an Ac_3 contraction (Fig. 11), abrupt when the iron is pure, but which spreads out when the iron contains carbon, oxygen, etc. A rounding of the Ac_3 hook at the beginning of the transformation $\alpha \rightarrow \gamma$ thus reveals the impurities of the iron.

The field of the α state, stable in the cold, extends from absolute zero to 920 degrees. In fact, radiographic analysis shows that the magnetic transformation of α iron at 770 degrees is effected

[7] Westgren. Loc. cit.

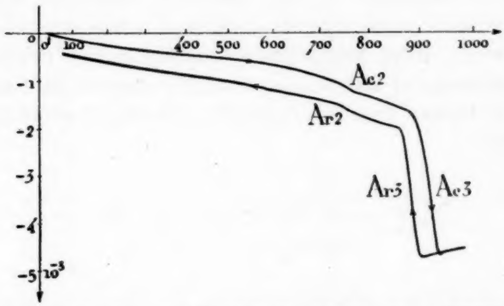

FIG. 11—DIFFERENTIAL DILATOMETRIC CURVE OF A SWEDISH IRON CONTAINING 0.03 PER CENT OF CARBON. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD. Ac_3 — Ar_3—ALLOTROPIC TRANSFORMATION α .. γ. Ac_2—Ar_2—THERMO-MAGNETIC TRANSFORMATION OF THE α IRON.

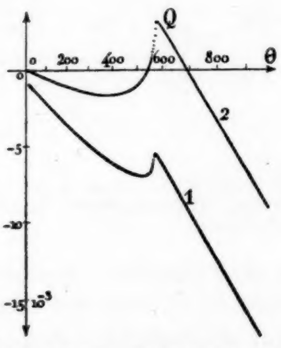

FIG. 12—EXPANSION OF QUARZ. MECHANICAL DILATOMETER. PYROS STANDARD. CURVE 1—ROD PERPENDICULAR TO THE TERNARY AXIS OF THE CRYSTAL. CURVE 2—ROD PARALLEL TO THE AXIS

without change of phase: it is no longer necessary to mention β iron as an isolated phase.

This magnetic transformation of α iron is marked by an anomaly of expansion Ac_2-Ar_2, obviously reversible, which consists in a rapid variation of the coefficient of true expansion in the region where strong magnetism disappears (Curie point).

The change of state of quartz at 570 degrees, with abrupt increase in volume (Fig. 12), is another example of allotropic transformation.

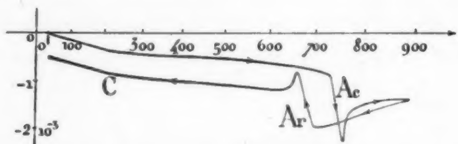

FIG. 13—DIFFERENTIAL DILATOMETRIC CURVE OF A EUTECTOID CARBON STEEL, C = 0.85 PER CENT. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD

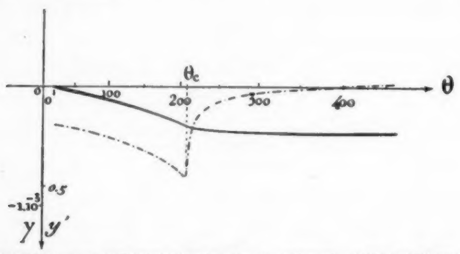

FIG. 14—ANOMALY OF CEMENTITE IN A STEEL CONTAINING 1.15 PER CENT OF CARBON. PHOTOGRAPHIC DILATOMETER. ELECTROLYTIC IRON STANDARD

4—Utilization of the Dilatometric Anomalies of a Phase to Distinguish Its Presence in an Aggregate

The expansibility of an aggregate does not obey the law of mixtures rigorously, but the variation is never important in comparison with the average of the expansibilities of the component phases. If one of these phases shows a dilatometric anomaly in the temperature range where the aggregate is stable, this anomaly appears on the expansion curve with an intensity almost proportional to the quantity of the anomalous constituent.

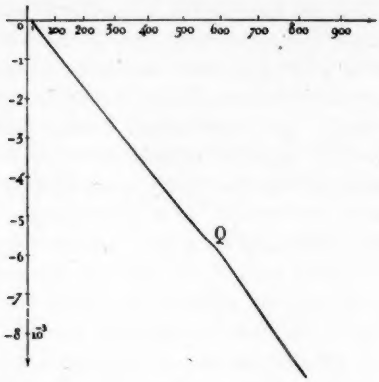

FIG. 15—EXPANSION OF A PORCELAIN. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD

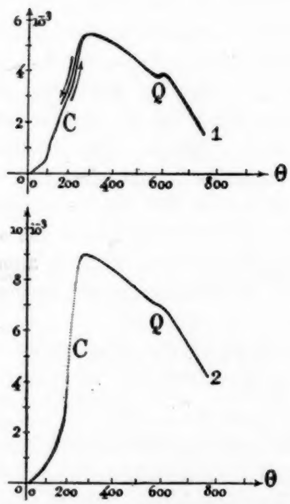

FIG. 16—DILATOMETRIC CONTROL OF THE BURNING OF SILICA BRICKS. MECHANICAL DILATOMETER. PYROS STANDARD. THE TRANSFORMATION OF THE QUARTZITE IS MORE COMPLETE IN BRICK NO. 2, AND THIS HAS THE BEST RESISTANCE TO FIRE

It is thus that the anomaly of cementite is met again in all aggregates in which this constituent exists in the free state: carbon steels (Figs. 13 and 14) and white cast irons (Figs. 24 and 25). A quantity of cementite corresponding to a carbon content of only 0.05 per cent appears on the expansion diagram after tracing the derived curve. This specific irregularity of iron carbide Fe_3C therefore constitutes a detector and also an element for quantitative measurement.

The anomaly of quartz Q is also seen in certain porcelains (Fig. 15) and in silica brick (Fig. 16). In burning these bricks the quartzite used as raw material is largely transformed into varieties of silica of low density, tridymite, cristobalite, etc., which possess, between 100 degrees and 200 degrees, the extremely pronounced irregularities of expansion C. But a certain amount of quartzite escapes transformation; the proportion can be estimated approximately from the magnitude of the anomaly Q and the efficacy of the burning can be thus measured.

As a final example, we shall cite the variation of the anomaly of the solid solutions (Cu + Al) — in aluminum bronzes with two constituents $\alpha + \gamma$. As Fig. 10 shows, the magnitude α of the anomaly decreases from 9.2 per cent to 16 per cent Al, the boundaries of the $\alpha + \gamma$ region. The experimental curve deviates quite sensibly from the straight line that would express the law of mixtures. It is true that the measurements are not very exact for alloys rich in constituent γ, for the anomaly of the α. solution tends to become entangled with the anomaly of the γ solution, probably of the same nature as the former.

5—Dilatometric Analysis of the Phenomena of the Mechanism of the Hardening of Alloys

Dilatometric analysis shows with extreme clearness the transformations that take place in steels during hardening; it permits a quantitative estimation completely defining the hardening power[8]. But even in the case where the phenomena are very slightly marked or very complex, the mechanism of the hardening can be

[8] A. Portevin and P. Chevenard. The "characteristic curves" of the heat treatment of steel. Journal of the Iron and Steel Institute, v. 104, p. 117 (1921).

discovered and studied. We shall cite, in particular, the following two examples:

1. In the light aluminum alloys capable of hardening (alloys Al-Al_2Cu and Al-Mg_2Si), the transformations that up this time have escaped direct thermal analysis have been disclosed and studied by means of the differential dilatometric method[9].

2. In an aluminum bronze with 12 per cent aluminum, we have shown the complexity of the phenomena, a complexity resulting from the intervention of a reversible labile state.[10]

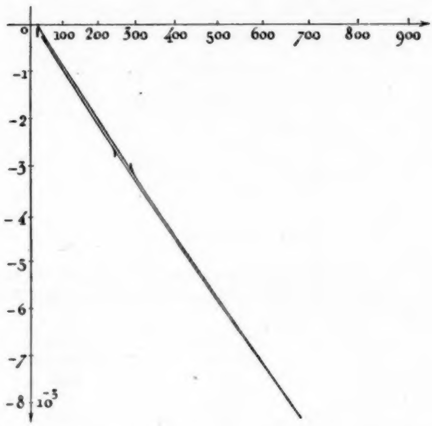

FIG. 17—EXPANSION OF GRAPHITE. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD

B—Study of Cast Irons

Dilatometric Characteristics of Their Constituents

There are found in ordinary cast irons, *ferrite, cementite* (metastable system) and *graphite* (stable system); and, when cooling after casting has been rapid, *austenite* and *martensite,* con-

[9] A. Portevin and P. Chevenard. A dilatometric study of the transformations and thermal treatment of light alloys of aluminium. Journal of the Institute of Metals, v. 30, p. 329 (1923).

[10] A. Portevin and P. Chevenard. Comptes-Rendus de l'Académie des Science, 1926, v. 182, p. 1143.

stituents of the chill. Steels contain the same constituents, with the exceptions of graphites.

The anomalies of iron and of cementite have already been pointed out: we shall explain briefly the dilatometric properties of the other constituents and their mutual reactions.

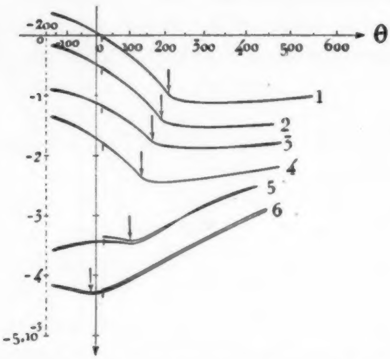

FIG. 18—ANOMALY OF THE COMPLEX CEMENTITES IN MANGANESE CAST IRONS. PHOTOGRAPHIC DILATOMETER—ELECTROLYTIC IRON STANDARD

Curve No.	Per Cent Carbon	Per Cent Manganese
1	4.80	0.00
2	4.70	0.75
3	4.26	1.62
4	4.65	2.88
5	4.20	4.06
6	4.14	8.10

1—Graphite

Fig. 17 relates to a sample cut from an Acheson electrode. A rod of Ceylon graphite agglomerated with sodium silicate gave an identical curve.

Graphite, but very slightly expandible, is free from thermal irregularities. This feeble expansibility entails the rupture of the flakes of graphite when the cast iron undergoes a transformation with an important change of length: whence swelling and porosity.

2—Complex Cementites

Manganese, chromium, vanadium, tungsten, etc., also form definite compounds with carbon; these carbides are associated with the cementite in special cast irons and steels.

Fig. 18 groups the curves of differential expansion obtained with cast irons all containing about 4.5 per cent of combined carbon and increasing proportion of manganese. It is seen that the

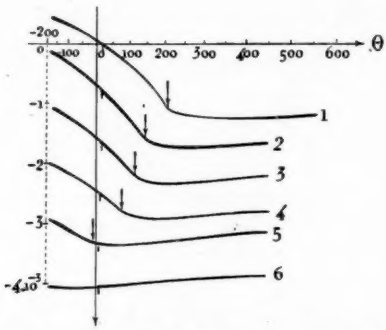

FIG. 19—ANOMALY OF THE COMPLEX CEMENTITES IN CHROME CAST IRONS. PHOTOGRAPHIC DILATOMETER — ELECTROLYTIC IRON STANDARD

Curve No.	Per Cent Carbon	Per Cent Chromium
1	4.50	0.00
2	4.80	2.05
3	4.50	2.88
4	4.30	3.71
5	4.25	6.30
6	4.38	8.78

Curie point recedes in continuous fashion, proof that *Mn_3C forms a solid solution with Fe_3C.* There are therefore no double carbides and this appellation, used hitherto, should be replaced by that of *complex cementites.*

An analogous conclusion concerning chromium cast irons is drawn from Fig. 19.

In these special cast irons, whose content of combined carbon is much the same (4.5 per cent), the depression of the Curie point

of the cementite is almost proportional to the content of manganese or chromium (Fig. 20).

Therefore, from the position of the Curie point of a cementite, one may estimate if it is pure or if it contains such an element as manganese, chromium, etc. By this method, the changes of com-

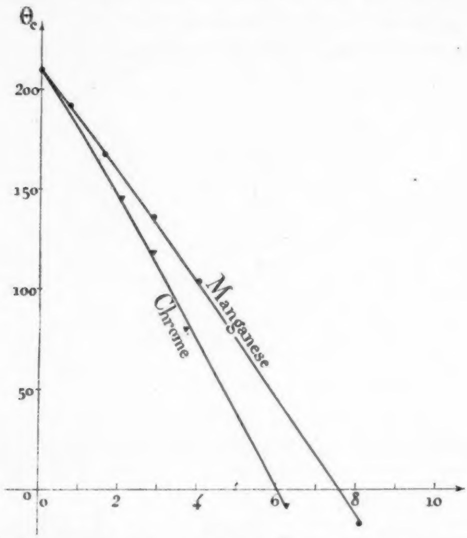

FIG. 20—VARIATION OF THE CURIE POINT OF THE COMPLEX CEMENTITES WITH THE CONTENT OF CHROMIUM OR MANGANESE, IN CAST IRONS HAVING APPROXIMATELY 4.5 PER CENT OF COMBINED CARBON

position of a complex cementite may be followed during the annealing of a steel.

3—Pearlite—Eutectoid Steel

Pearlite, iron-cementite eutectoid, is found in every iron-carbon alloy in the metastable state. To study its properties, we choose a steel with 0.85 per cent of carbon in the form of almost pure pearlite (Fig. 13).

Around 730 degrees the iron and the cementite react to give austenite, a solid solution of carbon in γ iron. The reaction,

isothermal as required by the phase rule, is indicated by a contraction.

The thermal phenomenon that accompanies it creates a difference of temperature between the standard and the steel rod. This variation tends to disappear as soon as the reaction ends. That is why the normal contraction is prolonged by a parasite hook[11]. But it is easy to exclude it and, attention being attracted to this accessory phenomenon, any false interpretation of the hook will be avoided.

Bend C is nothing but the anomaly of cementite.

4—Austenite

Pure austenite, solid solution of carbon in γ iron, is not stable below 700 degrees. However, it exists, in part, at the ordinary temperature when it is cooled very suddenly from a high temperature. This treatment, which shifts the transformation of equilibrium Ar: austenite $\rightleftarrows$ iron $+$ cementite, is called hypercooling; hypercooling, comparable to a superfusion, is very different from hardening proper, which gives rise to martensite.

Be the speed of cooling whatever it may, pure austenite cannot be obtained at an ordinary temperature, starting with an alloy formed only of iron and carbon only. It is necessary to use steel containing an addition, such as manganese, it being only necessary to take account of this foreign element in the quantitative interpretation of the results.

Fig. 21 outlines a manganese steel; C of 1.50 per cent; Mn of 2.05 per cent, hypercooled from 1150 degrees in water (the sample is compared with an electrolytic iron standard). At the begining of the experiment the alloy is non-magnetic and the microscope reveals austenite without martensite.

This austenite is very expandible, as the strong inclination of the curves 1, 2, 3 shows; furthermore, it is stable as long as the annealing does not go beyond 325 degrees, since these curves 1, 2 and 3 are almost reversible. However, a slight incurving from the heating can be noticed, which indicates progressive precipitation of the cementite: we will have occasion to refer to this phenomenon in a later study.

[11] See A. Portevin and P. Chevenard, Revue de Métallurgie, 1921, v. 18, p. 425.

At 350 degrees (cycle 4) the austenite decomposes suddenly with the liberation of heat: whence the extremely pronounced parasitic hook A. The cooling curve of cycle 4 is almost horizontal, proof that the iron is restored to the iron state. And as it shows a carbide anomaly C, it is concluded that the austenite has been decomposed into "ferrite+carbide."

But point C_1 is below 210 degrees; the carbide set free by decomposition of the austenite therefore contains manganese, this element dividing between the complex cementite and the ferrite.

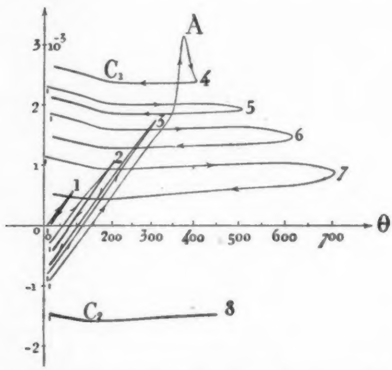

FIG. 21—COOLING CYCLES OF AN AUSTENITE OBTAINED BY SUPERCOOLING A MANGANESE STEEL C = 1.50 PER CENT; Mn = 2.05 PER CENT. PHOTOGRAPHIC DILATOMETER — ELECTROLYTIC IRON STANDARD

As the annealing continues, phenomenon C goes back. In steel annealed at 850 degrees (curve 8) the temperature of the anomaly C_2 is distinctly lower than that of C_1. Thus the coefficient of the division of the manganese between the carbide and the ferrite varies according to the annealing temperature, and dilatometric analysis makes it possible to observe this changing of composition.

5—Martensite

Martensite, a constituent of the hardening of steels, can not be obtained in a pure state. The transformation that gives rise to it takes place at a low temperature and is never complete: so mar-

tensite is always accompanied by an excess of austenite. Therefore the anomalies of expansion characteristic of the decomposition of these two constituents are superimposed in the curve of cooling.

Let us first quench an eutectoid steel at a very high temperature in order to obtain a considerable proportion of austenite in the martensite. During the tempering (Fig. 22) an important contraction is noticed, but the curve of the phenomenon is exceedingly variable, according to the temperature. One is led to consider that this curve expresses the resultant of two phenomena.

1. A continuous contraction that corresponds to the decomposition of the martensite.

2. A localized expansion, with a parasitic hook A, which more or less compensates the preceding contraction and which results from the decomposition of the austenite.

On the return, after cooling to 700 degrees, the cementite anomaly has exactly the same value as in the steel heated to 800 degrees. *Sorbite,* a constituent of tempering, is therefore an "iron+cementite" aggregate of the same composition as pearlite.

In a second experiment, let us quench the steel at only 800 degrees, in order to have a smaller excess of austenite, and describe the cycles of cooling (Fig. 23):

1. The cementite anomaly is zero in the steel quenched and cooled to 250 degrees: proof that the carbide in the martensite is in the state of solution and not in the form of cementite invisible under the microscope;

2. Anomaly C appears progressively and the curve of this restoration is exactly parallel to the diminution of the hardness.

C—Graphitization of Cementite

At high temperatures the metastable "iron-cementite" system tends to give rise to the more stable "iron-graphite" system. Silicon, aluminum, etc., assist the decomposition of cementite, while manganese, chromium, etc., by forming carbides more stable than Fe_3C, oppose graphitization.

Precise knowledge of the experimental laws of this phenomenon would be of great practical importance, either to foresee the manner of behaving of certain cast irons exposed in use to high

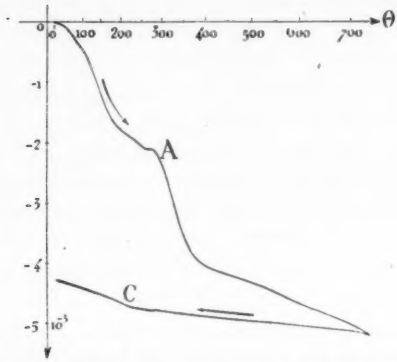

FIG. 22—COOLING OF A STEEL CONTAINING 0.85 PER CENT OF CARBON QUENCHED IN WATER FROM 1,150 DEGREES. PHOTOGRAPHIC DILATOMETER—PYROS STANDARD

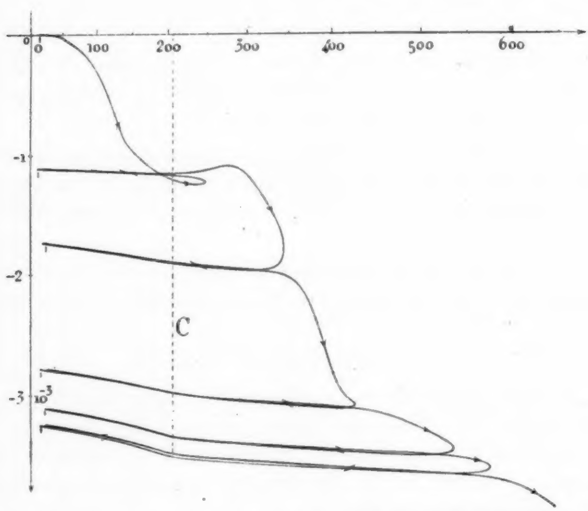

FIG. 23—COOLING CYCLES OF A EUTECTOID CARBON STEEL QUENCHED IN WATER FROM 800 DEGREES. PHOTOGRAPHIC DILATOMETER—ELECTROLYTIC IRON STANDARD

temperature or to guide the manufacture of malleable cast iron. Now the reaction: cementite → iron+graphite is accompanied by an important increase of volume: this is why we have taken up the dilatometric study of the graphitization of cast irons.

In commercial cast irons the phenomena appear *a priori* very complicated, because of the presence of several elements which all modify more or less the tendency toward decomposition of the cementite. It was therefore logical to subject to the tests first synthetic cast irons containing, besides iron and carbon, only a single addition: silicon, sulfur, manganese, etc. The combined action of these various elements, when they exist simultaneously in cast irons, will be investigated later.

But the chemical composition of the cast iron is not the only factor of the graphitization; the temperature reached in the liquid state and the rapidity of solidification, which determine the initial proportions of combined carbon and graphite, also intervene. This program of study therefore represents an important experimental work and, for the moment, we have only completed a part of it.

Therefore we shall content ourselves with showing, as an example, the results obtained with cast irons containing silicon. These test alloys have been prepared in a laboratory electric furnace, starting with pure elements: electrolytic iron, Acheson graphite, ferro-silicon containing 95 per cent Si, alumino-thermic manganese, etc. The melting temperature was controlled by means of an optical pyrometer. The alloys were cast at 1400 degrees in a cast iron ingot mold weighing 4 kg., into the form of rods 4 mm. in diameter. Under these conditions solidification is very rapid and the cast irons contain a high proportion of cementite, which favors observation. On the other hand, a true martinsitic hardening is generally proven, superimposed on the obtaining of the metastable state (tempering of cast irons).

In all the tests with the dilatometer, the rate of heating is almost constant and equal to about 250 degrees an hour.

1—Very Pure White Cast Iron

The diagram of Fig. 24 relates to a very pure cast iron, totally free from manganese and of which the carbon, 4.44 per cent, is entirely in the combined state; the silicon content is 0.24

per cent. The first cycle shows the reversible anomaly of cementite C in a striking fashion. On curve 2 are noted: during the heating anomaly C, the hook of transformation of pearlite Ac and, beyond 1000 degrees, a rise G; during cooling, the formation of pearlite Ac and the cementite anomaly.

On examining this cooling curve carefully, the cementite anomaly is seen to be less intense than at the beginning; this result is confirmed by micrographic observation which shows, after cycle 2, graphite particles. Hence phenomenon G expresses the

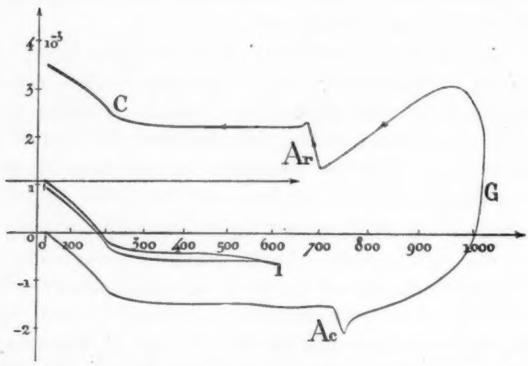

FIG. 24—WHITE CAST IRON, CAST IN BARS. C = 4.44 PER CENT; Si = 0.24 PER CENT; Mn = TRACE. PHOTOGRAPHIC DILATOMETER—PYROS STANDARD

graphitization of the cementite. In the cast iron investigated, very low in silicon, the reaction begins at a high temperature and continues slowly.

2—Graphitization of Silicon Cast Irons

Silicon has not only the effect of reducing the proportion of cementite formed during the cooling following casting, but it favors the decomposition of this cementite when the iron is brought to a high temperature. Hence, in the cast iron that contains 4.80 per cent carbon, 0.85 per cent silicon and 0.10 per cent manganese (Figs. 25 and 26), graphitization commences at 800

degrees (curve 3) and the phenomenon is rapid. The temperature having been raised to 1050 degrees, the cementite is totally decomposed.

Proof of this is had by tracing again expansion cycles after

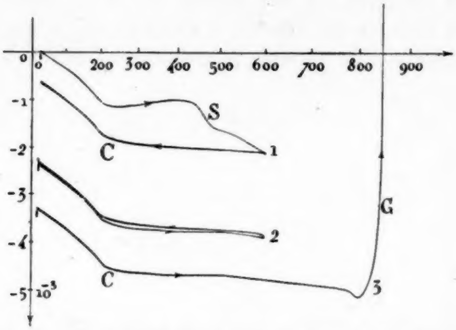

FIG. 25—SILICON WHITE CAST IRON, CAST IN BARS. C = 4.80 PER CENT; Si = 0.85 PER CENT; Mn = 0.10 PER CENT. PHOTOGRAPHIC DILATOMETER—PYROS STANDARD

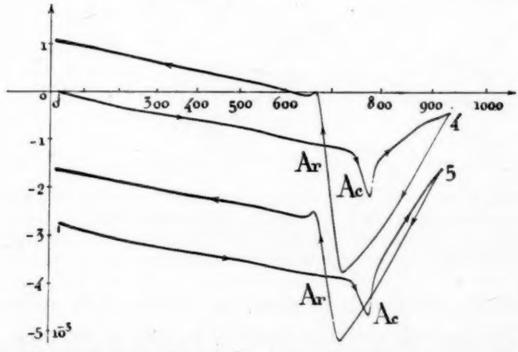

FIG. 26—SILICON CAST IRON, CAST IN RODS AFTER GRAPHITIZATION. SAME SAMPLE AS IN TEST OF FIG. 25. PHOTOGRAPHIC DILATOMETER—PYROS STANDARD

phenomenon G (cycles 4 and 5 of Fig. 26). The appearance of the diagram has undergone a profound change: the cementite anomaly has practically disappeared and the hooks Ac, Ar, correspond to the stable "iron-graphite" system. On the other hand,

after phenomenon G, the brinell hardness of the cast iron has moved from 400 to 100 kilograms per square millimeter.

We decided to take up the quantitative study of this accelerating role of silicon upon the graphitization of cementite. For this purpose we prepared, by the process indicated above, and then investigated with the dilatometer, a series of cast irons, free from manganese, containing variable proportions of carbon and silicon.

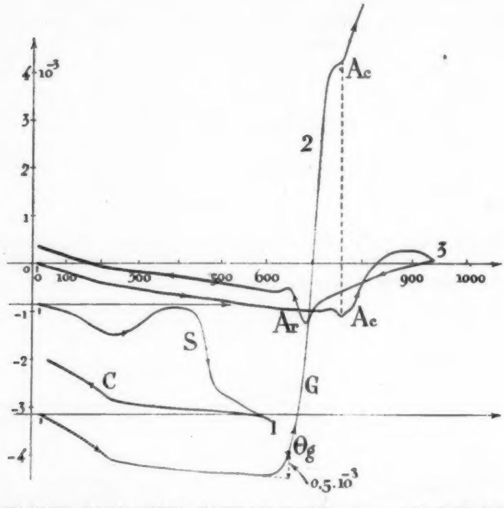

FIG. 27—SILICON CAST IRON, CAST IN RODS. C = 4.85 PER CENT; Si = 1.70 PER CENT; MN = TRACE. PHOTOGRAPHIC DILATOMETER—PYROS STANDARD. DETERMINATION OF THE CHARACTERISTIC TEMPERATURE OF GRAPHITIZATION θg.

It is important first to define the temperature of graphitization. The beginning of this reaction is hard to perceive, for the dilatometric curve deviates progressively from its original direction before rising in an accelerated fashion. To mark the position of the phenomenon on the temperature scale we shall agree to choose the point θg for which the linear expansion due to graphitization equals O, 5. 10^{-3}: this distance is counted, starting from the dotted curve (Fig. 27) that prolongs the portion of the graphitization curve.

It is seen (Fig. 28) how the temperature θg varies as a function of the silicon content in a series of cast irons containing about 4.20 per cent of total carbon. The arrangement of the experimental points is favorable to the hypothesis of a continuous variation of θg as the silicon content increases. This temperature θg diminishes rapidly at first, then tends to become stationary at about 610 degrees.

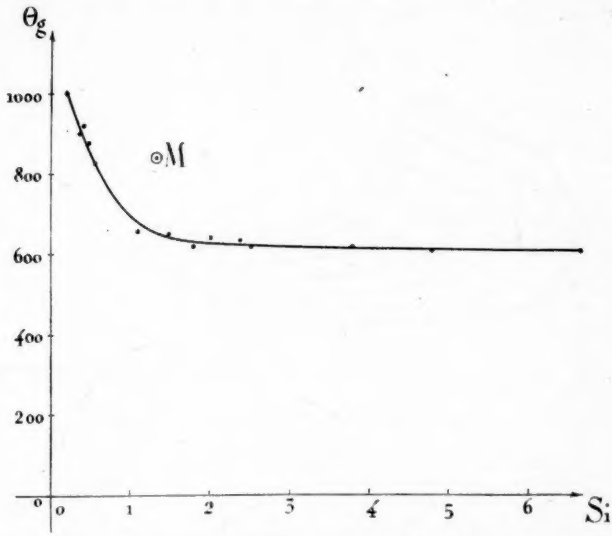

FIG. 28—VARIATION OF THE TEMPERATURE OF GRAPHITIZATION WITH THE SILICON CONTENT, IN A SERIES OF CAST IRONS CONTAINING APPROXIMATELY 4.20 PER CENT OF TOTAL CARBON. POINT M REFERS TO A MANGANESE CAST IRON WHICH CONTAINED: C = 4.20 PER CENT; Si = 1.34 PER CENT; Mn = 4.06 PER CENT

The perspective diagram of Fig. 29 summarizes the results of these experiments. It relates to alloys of which the carbon content extends from 1.7 to 4.5 per cent and the silicon content from 0.2 to 6 per cent. In this range of composition, the surface (θg, C, Si) is represented by two sets of lines. One of these expresses the influence of silicon for constant total carbon: 1.7; 2; 2.5......4.5 per cent. The other sets are the isotherms of

graphitization arranged at intervals from 650 to 1000 degrees. The arrangement of the isotherms shows in quantitative fashion, the well known result that silicon and carbon unite their effects to favor graphitization. But these results cannot pretend to show completely the role of silicon in the presence of carbon. They relate to cast irons prepared at 1400 degrees and cast in thin rods: the influence of the melting temperature and of the speed of cooling remain to be elucidated.

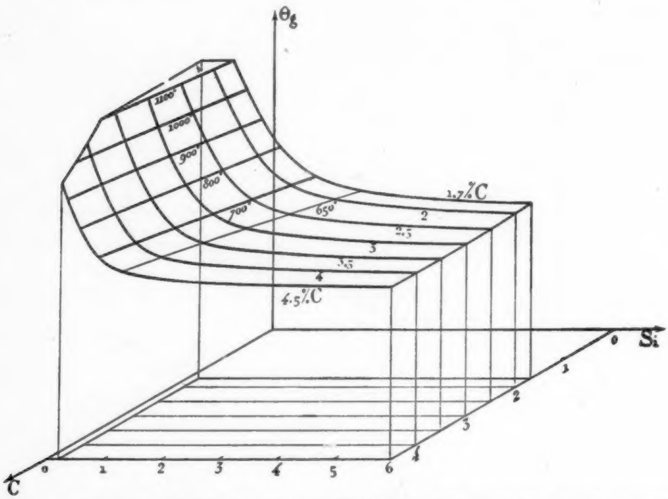

FIG. 29—TEMPERATURE OF GRAPHITIZATION OF SILICON CAST IRONS

The dilatometric diagrams of Figs. 25 and 27 require another remark: the first thermal cycle shows a cooling irregularity S, analogous to that which we encountered in the hardened steels. Therefore, casting in chill molds can cause two very distinct phenomena, although both are designated by the name of hardening.

1. The production of the metastable system: iron-cementite; cast iron hardening.

2. Obtaining of martensite; steel hardening.

3—Complex Phenomena Observed in a Cast Iron Containing Silicon and Manganese

Manganese tends to counteract the action of silicon in graphitization: thus in Fig. 28 the point M, relating to a cast iron containing both silicon and manganese, is placed at a notable distance above the curve of the silicon cast irons.

On the other hand, manganese intervenes in the constitution of the complex cementites: finally, it renders iron-carbon alloys

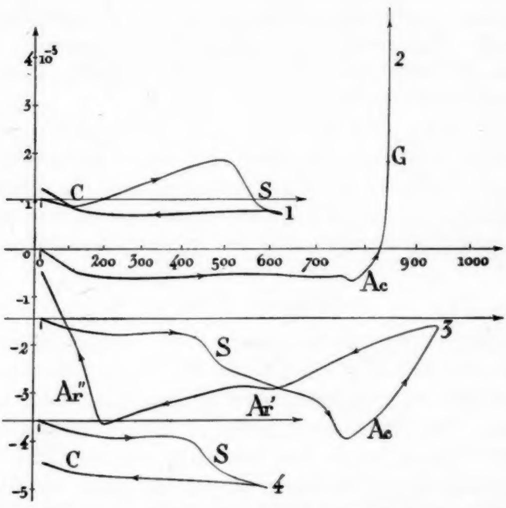

FIG. 30—SILICON-MANGANESE CAST IRON, CAST IN RODS. C = 4.20 PER CENT; Si = 1.34 PER CENT; Mn = 4.06 PER CENT. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD

self-hardening. One therefore expects to observe complicated manifestations during the cooling of a cast iron containing both silicon and manganese and cast in chill molds. We shall show, by an example, that dilatometric analysis permits unraveling of the entangled phenomena.

The cast iron studied (Fig. 30) contains 4.20 per cent of carbon, 1.34 per cent of silicon and 4.06 per cent of manganese. Cycle 1 first shows around 125 degrees the anomaly of a complex

carbide; then the curve takes an upward direction. After an irregularity S it becomes almost horizontal and preserves this direction during the cooling until point C, where the carbide anomaly appears with increased intensity. The explanation is easy: the iron, cast in 4 mm. rods, was partially supercooled, that is to say, contained a certain quantity of austenite with the martensite: whence great expansibility. This austenite and this martensite retained carbon in solution: cooling precipitates the carbide (irregularity S) which caused anomaly C to increase.

On curve 2 the graphitization G appears beyond 800 degrees: that is to say, nearly 200 degrees higher than if manganese were not present. The return of the cycle is not recorded but, as manganese diminishes the critical speed of hardening, a self-hardening in the course of the cooling is foreseen.

This is clearly what appears in cycle 3: the cooling irregularity proves the existence of a prior hardening. Moreover, during the cooling of this cycle 3, the transformation Ar divides into two manifestations Ar′ Sr″, and this aspect corresponds precisely to a self hardening, confirmed in its turn by the irregularity S of cycle 4.

4—Influence of Sulfur

Contrary to the opinion accepted by certain metallurgists, sulfur does not appear to exert a sensible influence on the decomposition of cementite, at least, when the proportion of it is below 1 per cent. The dilatometric curves of Fig. 31, although traced up to 1050 degrees, are in fact free from the rise which characterizes graphitization; softening of the test piece, by fusion of the eutectic, can even be obtained without observing this rise.

Around 130 degrees, the curves of the two cast irons richest in sulfur present a slight irregularity, the study of which appears interesting: we propose to undertake it with a new dilatometer of great sensitiveness.[12]

D—Applications of Dilatometry in the Foundry

These applications relate either to the *physico-thermal analysis* of foundry cast irons and alloys or the *measurement of the expansibility of materials.*

[12] P. Chevenard. Dilatomètre differéntiel triple. Bulletin de la Société Francaise de Physique, no. 222, November, 1925, p. 113S.

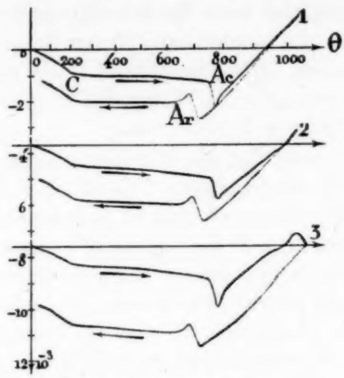

FIG. 31—SULFUROUS WHITE CAST IRONS.

Curve No.	Per Cent Carbon	Per Cent Sulfur
1	3.32	0.090
2	2.69	0.46
3	2.64	1.05

MECHANICAL DILATOMETER. PYROS STANDARD.

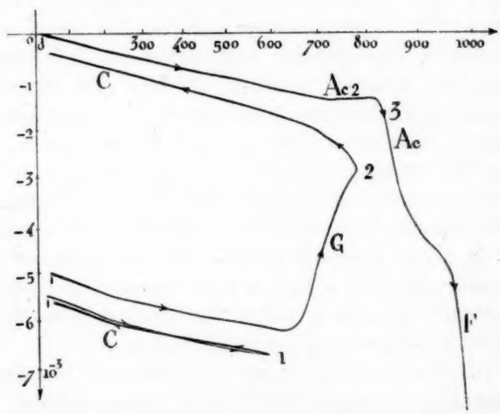

FIG. 32—PHOSPHORIC FOUNDRY IRON. C = 3.30 PER CENT; Si = 2.10 PER CENT; Mn = 0.40 PER CENT; S = 0.060 PER CENT; P = 1.35 PER CENT. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD

In commercial cast irons the transformation phenomena are generally multiple and tangled, but dilatometric analysis very frequently permits them to be interpreted. Thus the cycles of Fig. 32 elucidate the succession of phenomena which occur during the heating of a phosphoric foundry iron.

Anomaly C shows that the cast iron initially contained about 1 per cent of combined carbon. The silicon content being high in comparison to the proportion of manganese, graphitization begins at 600 degrees, as is seen on curve 3, practically free from anomaly C. This curve 3 shows, near 730 degrees, the anomaly Ac_2 of ferrite with silicon: it is known, as a matter of fact, that silicon lowers the Curie point of α iron. Next is seen the hook Ac which shows the transformation of the stable system. Finally, the temperature of the drop F coincides with the melting temperature of the ternary phosphorous eutectic: about 950 degrees. This drop thus corresponds well to the sagging of the sample under the slight pressure of the dilatometer springs.

As a second example we shall reproduce the diagram obtained with a cast iron for rolling-mill rolls (Fig. 33).

The sample studied was cut from a fragment of the chilled outside of a roll. The successive cycles between 550 degrees and 950 degrees cause a progressive expansion that shows a gradual graphitization of the cementite. This cementite, containing a little manganese and relatively small in quantity (the percentage of carbon is below the customary content of these cast irons), is in a condition of average stability and decomposes slowly.

Thus, the dilatometric method makes it possible to estimate the greater or less ease of decomposition of the cementite. Without doubt, success in describing quantitatively *the graphitizing tendency of a cast iron* will be attained, just as the defining of the *hardening power of a steel* is now known. One understands the importance of such a result for guiding scientifically the manufacture of black-heart malleable castings.

On the other hand, by means of differential dilatometers we have determined the expansibility of a certain number of substances used in foundry practice: steels, cast irons, bronzes, aluminum-copper alloys, alpax, refractory products, enamels, etc. It appears to us interesting to state the results obtained in the

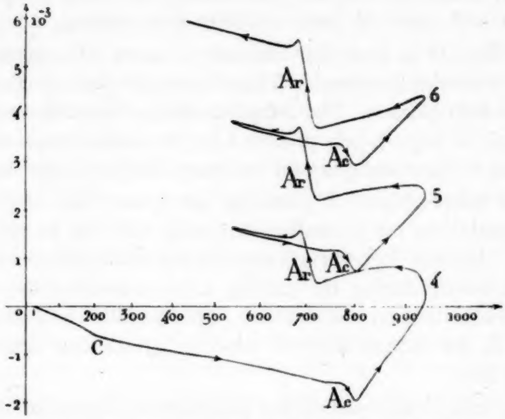

FIG. 33—SURFACE FRAGMENT OF A CHILLED CAST ROLL. C = 2. 60 PER CENT; Si = 0.95 PER CENT; Mn = 0.25 PER CENT; S = 0.075 PER CENT; P = 0.490 PER CENT. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD

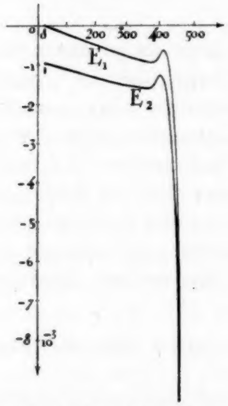

FIG. 34—ENAMEL FOR THE DECORATION OF CAST IRON. PHOTOGRAPHIC DILATOMETER. PYROS STANDARD. E_1 = GOOD ENAMEL; E_2 = CRACKED ENAMEL

study of enamels used for decorating cast iron. The glazes obtained with some of them crackled upon cooling.

In Fig. 34 is seen the dilatometric curve of a good enamel and of a cracking enamel. Their course is that of the curves obtained with glasses. The softening characterized by sagging of the sample is immediately preceded by the sudden expansion that, according to Samsoen, precedes the pasty fusion of vitreous bodies.

The temperatures of softening are almost the same for the two enamels, but the expansions are very different in the field of rigidity. Enamel E_2 contracts appreciably more than the cast iron to be covered: during the cooling after enameling the glaze is placed under tension and cracks. This accident is avoided with enamel E, the expansibility of which is a little less than that of the cast iron.

We have finally shown the dilatometric control of the burning of silica brick.

E—Conclusions

1.—It is seen, by these examples, that all the phenomena of cast iron now known have their indication on the expansion curves.

In particular, we have found again the principal results of Charpy, Grenet and Cornu-Thénard[13], relating to graphitization and obtained by examination after quenching at different temperatures. But the dilatometric method is quicker, easier, more sensitive, more direct and clearer. It is also more certain, for it separates the phenomena that act during the hardening of the samples. It, in short, permits continuous measurements, and this continuity appears necessary to untangle very complicated phenomena, such as those that we have observed in a manganese cast iron.

2.—Dilatometric analysis possesses, like chemical analysis, a double aspect.

(a)—*Qualitative analysis.* Specific anomalies at definite temperatures, like those of cementite, mark the presence of phases; definite compounds or solid solutions, the chemical composition

[13] Comptes-Rendus de l'Académie des Sciences, 1902, v. 134, p. 103; and 1913, v. 156, p. 1616.

of which is known. Examples: complex cementites and constituents of meteoric irons[14].

But although chemical analysis indicates only the total composition of an aggregate, dilatometric analysis gives information about the nature of the components and so constitutes a process of *proximate analysis.*

(b)—*Quantitative analysis.* The magnitude of the anomalies of which we have been speaking furnishes a process of *quantitative* estimation of the constituent whose presence is thus revealed: estimation of the amount of free cementite contained in a steel after various treatments. Furthermore, Tammann's method for the quantitative investigation of invariant, isothermal reactions can be transposed to dilatometry. It suffices to study as a function of concentrations, the magnitude of the dilatometric phenomenon corresponding to the reaction, to find by extrapolation the concentrations of the reacting phases.

This generalization can be extended to all the physical methods, which offer the advantage over the thermal method of not requiring corrections of the magnitude to take account of variations in the rate of cooling: from this general method of physico-thermal analysis, we may expect interesting results for the establishment and the revision of equilibrium diagrams.

3.—Dilatometric analysis is suited not only to massive test pieces obtained by casting or by machining, but to rods prepared by the agglomeration of powdered substances. By this method Bræsco[15] has studied the specific irregularities of different varieties of silica, and Chaudron[16] the thermal transformations of the iron oxides. It is thus possible to analyze the industrial reactions that occur in a solid medium: calcining, cementation, etc.

4.—Finally, independent of thermal analysis, the differential dilatometer enables the expansibility of materials to be determined over a great temperature interval. This measurement, of evident scientific importance, affects also numerous industrial problems: the selection of the materials forming the parts of heat engines or refrigerating machines, glass equipment in the manufacture of optical instruments and artistic glassware, choice of electrodes for welding to glass, foundry enamels, etc.

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[14] See A. Portevin and P. Chevenard. Revue de Métallurgie, 1921, v. 18, p. 290.
[15] P. Braesco. Thesis. University of Paris, 1920.
[16] G. Chaudron and H. Forestier. Comptes-Rendus de l'Académie des Sciences, 1924, v. 178, p. 2173.

Discussion

E. J. Lowry: This paper is highly theoretical and very technical, but it does carry a mass of information which will apply some day to the foundry industry. The work which I have been carrying on has not been so accurate. I have been carrying it on in a practical way, more to see whether I could value quality of materials by expansion, using what we call a Rockwell dilatometer. It is not an extremely fine instrument, it is an instrument originally designed for the purpose of hardening steel. The method of operation is to take a sample of a definite size, heat it at a definite rate and cool it at a definite rate, with a suspended rod attached to an arm, which is again attached to a recording device. As you heat the piece up, you get the expansion, which is measured by that device. I have found that my original expectations have not matured. It is pretty hard to tell quality of materials, as far as iron is concerned—that is the only thing I was concerned with—by measuring the expansion and contraction. However, I have found this, that as you take a silicon iron, for instance, taking first a 1.25 silicon, and then go to a 1.50, 1.75 and so on upward, you do get increased expansion as you increase your silicon. It would seem almost that you would be able to determine the silicon content of pig iron of definite constitution by dilatation. That point caught quite a little of my attention and I sent to the laboratory of Crompton and Knowles a number of samples of pig iron, not caring which irons I took them from, but varying the analysis. In some cases I got extremely wide variations in expansion and contraction, depending upon where the iron was made and what was put into it. This led me to conclude that in order to get expansion and contraction to be of any value, you would have to know the source of origin of a pig iron.

Then, continuing the experiment a little further, we took the pig irons that we examined under the dilatometer and melted them and put them into castings. We found that invariably the characteristic expansion curve of pig iron would come through right to the casting.

We found also that if you heated a piece of iron, first taking the expansion of the piece, then heated it and quenched it, you did not materially affect the curves. In other words, the diagram of the curve was the same. The only thing you did was to shorten the amount of expansion by the quench. That would seem impossible, you would expect that as the combined carbon increased in that piece of iron, the expansion would increase, and that is what we expected, but the results obtained were the reverse.

One other point that was brought out was that if an iron was made in a blast furnace that was slipping, that is, not working perfectly, the character of the curve immediately showed a marked drop. In other words, the average curve went up usually on a contour fairly smooth, with a few drops or indentations in the curve. This paper explains some of

the causes of these effects that I never could have explained in a life-time. Now, then, as this furnace produced a bad pig iron, that curve would go up in its natural form, possibly a little sharper, then would drop immediately down and then come back to the level. In other words, there was some phenomenon going on in there which reacted on the expansion, so that although I am not positive yet that we can tell quality pig iron by the use of a dilatometer, the more work that we do on it, the more evidence we get that the dilatation of cast iron becomes an important feature, and it is a factor which is controlled more or less by the materials that you people put in your cupolas. It might be interesting to add that if you should use your sample once and then you want to check yourself, the curve, in its contour, doesn't change, but the expansion grows a little bit later on the second heating and on the third heating. That is the most number of times I heated the sample. But the contour doesn't change, showing that certain properties which are definite in the iron remain there, even after re-heating.

Some Gray Iron Problems

By John Shaw,* Sheffield, England

It is with a certain amount of diffidence that the somewhat heterodox views contained in this paper are put foward for consideration. The only justification for so doing is the fact that they are the outcome of four years' observations of the results of roughly 800 complete analyses, in which the losses or gains of each element from the calculated analysis, after passing through the cupola, have been noted. While in some cases no definite conclusions have been reached, it is hoped that the discussion which follows will help to fix these.

Purpose

It is proposed to consider the influence of sulphur and manganese on the structure of cast iron containing ordinary amounts of the other usual elements, and to deal with the influence of carbon and silicon, in conjunction with the other elements, on the structure, and finally the usefulness of various chill tests to the practical man for judging roughly the ultimate structure of his molten metal, before casting, especially if using much foreign scrap.

No analysis has been included unless there has been at least four tons of the same material following the tested ladle, so no

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This paper is one of a series on foundry problems being exchanged between the Institute of British Foundrymen and the American Foundrymen's Association. The first, prepared by George K. Elliott, was presented to the 1921 meeting of the I. B. F The second was presented at the Rochester, New York, meeting of the A. F. A. by F. J. Cook, past president of the I. B. F. Professor Enrique Touceda presented the third paper before the British Society in 1922. The fourth was written by Dr. Percy Longmuir; the fifth by Major R. A. Bull; the sixth by Wesley Lambert and G. Hall; the seventh by R. J. Anderson and M. E. Boyd; the eighth by J. E. Fletcher; the ninth by Dr. H. Ries; the tenth, the 1926 A. F. A. paper before the I. B. F., was prepared by Arnold J. Lenz. This, the eleventh of the series by John Shaw on behalf of the Institute of British Foundrymen, is a worthy contribution to this the Second International Foundrymen's Congress. Mr. Shaw, the author, has been prominently connected with the British foundry industry all his life and is at present manager of the Newhall works of the Brightside Foundry and Engineering Company of Sheffield. He joined the Institute of British Foundrymen in 1906, was president of the Birmingham branch for three years and is now president of the Sheffield branch. Mr. Shaw is the third oldest British member of the American Foundrymen's Association, which he joined in 1910. As a fitting tribute for his distinctive and valuable service to the foundry industry of Great Britain, Mr. Shaw was presented with the Oliver Stubbs gold medal in 1924 by the I. B. F.

contamination from a different mixture was probable. To enable the practical man to judge the structure and check these results, a chill test was used and the depth of the chill measured to the first few spots of grain showing. The test pieces were 6-inch by 4-inch by 1¼-inch thick, molded in dry sand cores, and placed on a chill 8-inch by 6-inch by 1½-inch thick. After casting from a pot ladle taken from the large ladle, the test piece was allowed to stand eight minutes, then slowly sprinkled with water, first on one side and then the other, until black hot, after which it was quenched out, broken, and the depth of the chill measured.

The Sulphur Question

Starting with sulphur, it is noted that not long ago nearly every ill in the foundry was attributed to this element. Today there is a danger of rushing to the other extreme. To quote only one authority, "A summary of most recent work goes to prove that sulphur in commercial cast irons, in the presence of sufficient manganese, exists almost wholly as the sulphide of manganese. In this form it is practically without influence on the structure and properties of cast iron." Now push this statement to its logical conclusion. It means, if it means anything, that it does not matter what sulphur your scrap contains. It does not matter if you use a high sulphur coke (for there are good low ash, good structure cokes with high sulphur), for you have only to raise the manganese content of your pig iron, and no ill effects will follow. You try this theory out on thin work and I am afraid you will be sorry.

Manganese-Sulphur Balance

We hear a great deal at the present time about manganese-sulphur balance. What exactly is meant? We know what is inferred. To attain this ideal condition, is manganese to be present in the atomic ratio to sulphur of 1.73 to 1, or are we to have the excess mentioned in the American car wheel specification of 3 manganese to 1 sulphur? Or need we go to the ratio of 8 to 1 found necessary by the late Dr. Stead in his experiments on mild steel, before he found all the FeS converted into MnS? What

about the vital issues of time and temperature found under cupola conditions, on these reactions?

Furnace Temperatures

The following statements all apply either to cupola or air furnace conditions as worked commercially, and not with a cubic centimeter of iron melted in a crucible in an electric furnace and held stewing at any temperature and time you wish. Once cupola metal is tapped into the ladle only a comparatively short time is available for any further reaction to take place before the metal is too cold to cast into molds. There are only about two investigations giving the internal working temperatures of cupolas. One was reported in the U. S. Bureau of Mines Bulletin No. 54. Coke only was used in this experiment and under these conditions a temperature of about 1550 degrees Cent. was registered. A more recent experiment[1] under ordinary working conditions was carried out at Sulzer Bros., at Winterthur. Provision was made through the shell of the cupola for the insertion of platinum and platinum-rhodium pyrometers, at different levels, these results being checked by Wanner pyrometers at the same height through other holes in the shell. The highest temperature registered was 1484 degrees Cent.

Now these results may not be entirely reliable, owing to the difficulties encountered, but there are endless correct data with regard to tapping temperatures. Emmel, with his specially arranged cupola and conditions, gives us temperatures up to 1475 degrees Cent., but this is not usual for ordinary work. The figure of 1370 degrees Cent. as an average given by Mr. Allison represents good ordinary practice. When this metal falls into the ladle a drop of 38 degrees Cent. may be expected. Elliott found, from a mass of data, that molten gray iron may drop in temperature from 55 degrees Cent. to 165 degrees Cent. in the time between leaving the cupola and entering the mold. From this we may take it that 1300 degrees Cent. to 1350 degrees Cent. is a good average casting temperature.

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[1] Stahl und Eisen, June 25, 1925. Translated in Foundry Trade Journal, Aug. 13 1925.

Manganese and Sulphur

The melting point of manganese sulphide is variously placed. One gathers from a perusal of published work that sulphide of manganese is insoluble in molten cast iron at the temperatures commonly found in cupola work. The melting point most generally accepted is the one put forward by Röhl in his Carnegie research for 1912. He placed this at 1620 degrees Cent. McCance agrees that this figure is the most reliable, and attributes the lower figures obtained by other workers to the presence of man-

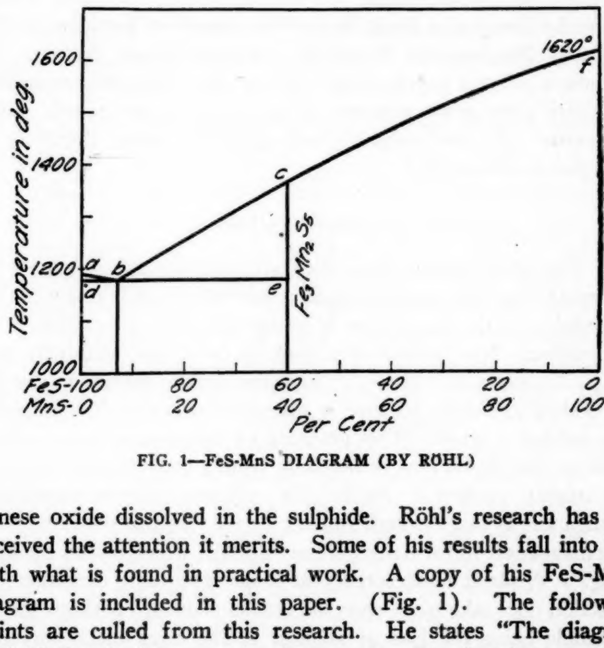

FIG. 1—FeS-MnS DIAGRAM (BY RÖHL)

ganese oxide dissolved in the sulphide. Röhl's research has not received the attention it merits. Some of his results fall into line with what is found in practical work. A copy of his FeS-MnS diagram is included in this paper. (Fig. 1). The following points are culled from this research. He states "The diagram FeS-MnS falls into two simple systems. The first between FeS and a compound $Fe_3Mn_2S_5$, with 60 per cent FeS and 39.75 per cent MnS; and the second between this compound and pure MnS. There is evidence that at about 60 per cent FeS a chemical combination takes place between the FeS and MnS, giving the above

formula $Fe_3Mn_2S_5$, with a melting point of 1360 degrees Cent., and that an unlimited solubility exists between this compound and an excess MnS, even in the solid state present in the melts. A continuous series of mixed crystals accordingly exists between the combination $Fe_3Mn_2S_5$ and the final member MnS, these mixed crystals differing thermally from each other in the fact that their freezing point is always shifting higher, reaching and exceeding, with a percentage of 30 per cent FeS, the freezing point of pure iron."

Röhl also claimed that the reaction $Mn + FeS = MnS + Fe$ is reversible. Although this was not accepted by McCance, a recent paper by Herty and True, before the American Institute of Mining and Metallurgical Engineers, confirms Röhl's finding. The summary of this paper states "The results show that manganese sulphide, even in the presence of an excess of manganese, will be converted into iron sulphide and enter the metal, therefore the reaction is reversible."

Loss of Sulphur

The above points have been stressed because it is generally accepted that even under cupola conditions there is a distinct loss of sulphur if the manganese is in the ratio of not less than 3 to 1 of sulphur. Nearly every text book on the subject definitely states this. To quote only two—"A high manganese content in cast iron is desirable, chiefly because it operates favorably in diminishing the sulphur content. This property of manganese renders it possible to free *liquid iron in the ladle* from a considerable portion of its sulphur content." Again, "In ordinary practice considerable manganese is lost through sulphur in the mixture combining with the manganese to form manganese sulphide, which passes off in the slag." While it is accepted that under favorable conditions this reaction does take place with the results claimed (perhaps the best example being the loss of sulphur in the large metal mixers at steel works, where both time and temperature play a part, but more especially the lime and ore additions which create a favorable slag), we have never found much loss of sulphur under ordinary foundry conditions by raising the manganese. If you take a test from a very hot ladle and quench at once, and another when

the iron is as cold as possible, there is little or no difference in the sulphur content.

Since writing the above, a paper[2] by Meierling and Denecke has appeared, a summary of which is as follows:

1. In the case of strongly overheated irons a quite perceptible desulphurisation occurs after a definite drop in temperature, and is due to segregation or solidification of mixed crystals rich in iron and manganese sulphide.
2. Desulphurisation occurs not only with high sulphur alloys but also in cast irons having a normal sulphur content.
3. In thickly liquid cast irons there is no desulphurisation, because the manganese and iron sulphides which form are prevented from rising by the viscosity of the bath.
4. No effect of shaking the bath on desulphurisation could be found.

In the first cast a drop of sulphur from 0.216 per cent in the first ladle to 0.122 per cent occurred after decanting into other ladles ten times from a good height. Even in result 3 the metal was decanted nine times, proving at least that at first a fair temperature was attained. The whole paper is useless because no data are given as to furnace tapping temperatures, or even the final casting temperatures. However, to try this out we repeated experiments that had been done a number of times, using a metal of about the composition mentioned in the paper. We charged a small cupola with a suitable iron. In order to obtain a high cupola temperature, a slight excess of coke was used, and about 448 pounds of iron tapped out in the ladle to ensure a warm ladle and hot bed. This iron was poured into pigs. The ladle was then filled with 900 pounds of hot iron (approximately 1430 degrees Cent.) and a test taken. It was held for 27 minutes, and was then as cold as would enable the metal to leave a nearly clean ladle. A second test was then taken. The resulting data are given in Table 1. These results are in line with our previous work. The metal was hotter than is generally found in foundry practice, and was at the finish as cold as suitable to run ordinary castings.

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[2] Giesserei Zeitung, April 1, 1926.

It is difficult to estimate what takes place in the cupola, owing to so many possibly varying conditions, but for four years, for certain reasons, we have had the gain or loss of each element between the calculated and actual result from the first ladle, at least twice per week. For our first two or three ladles we know the analyses of all the materials composing the charge, even the scrap, which is the return from a previous cast. A test is taken from the first ladle of metal and as at least one or more ladles of the same mixture follow, we know no contamination is probable. *The manganese and sulphur loss or gain given was actual,* not percentage. Taking these returns out for 1924, 83 complete estimations for gain or loss had been made. Neglecting the carbon, silicon

Table 1

TEST OF IRON FROM LADLE OF SPECIAL HOT IRON

	Analysis of 1st Test Temperature approximately 1430 degrees Cent.	After 27 minutes Temperature approximately 1220 degrees Cent.
Manganese, per cent	0.36	0.37
Sulphur, per cent	0.219	0.216
Chill test, depth in inches	1⅞	1⅝

Test from a Standard Ladle

	Analysis of 2nd test	When cool—approximately 1220 degrees Cent.
Total carbon, per cent	3.02	3.00
Silicon, per cent	0.75	0.72
Manganese, per cent	0.338	0.338
Sulphur, per cent	0.093	0.096
Phosphorus, per cent	0.48	0.47

and phosphorus results, it was found the loss of manganese between the calculated and actual varied between 0.09 to 0.23 (the greater loss always took place the higher the manganese charged, irrespective of sulphur), while the sulphur gain did not vary much, 0.034 to 0.038. To obtain an exaggerated view, all returns where the manganese loss was 0.2 and over were taken, and the sulphur content placed alongside. These numbered 21. The returns with a manganese loss below 0.12 with their sulphur gains were next compiled; these numbered 15. The sulphur gain in the first case was 0.038, in the latter 0.034, easily within analytical error. While on the subject of sulphur it would be as well to give a warning against expecting anything like true results by employing the evolution method on cast irons with sulphur 0.1 per cent or over;

no returns received have ever been within 20 per cent from any source.

While the cupola figures are open to question, even if they do extend over 12 months, due to slag conditions and varying sulphur in the coke, certain experiments carried out in the air furnace will stand examination. We make a fair amount of special low carbon iron for diesel engines and similar work. This is used both in England and to a greater extent on the Continent. This specification is fairly stiff, not so much in the margins allowed, but in the low and high range asked for. The specification in one case runs—total carbon 2.0 to 2.5 per cent, silicon 1.0 to 1.3 per cent, manganese 2.0 to 3.0 per cent, sulphur as high as possible, phosphorus below 0.4 per cent. To reduce the carbon in the air furnace, much of the manganese and silicon go with it. To bring back these elements to meet the specifications, FeMn and FeSi are melted in a small cupola. This metal is added to the large ladle when tapping the air furnace. One example worked out as follows—three tons of the alloy metal were taken from the cupola and poured into the large ladle receiving the air furnace metal. This ensured a good mixing. The large ladle was lifted out of the pit and the iron run into pigs. The time from tapping the air furnace to the solid pigs may be anything up to 30 minutes. As the manganese to sulphur ratio in this case was about 16 to 1 you would expect a fair loss of sulphur under these conditions. Tests were taken from the metal as it ran down the spout, to get a fair average of the air furnace metal. Tests were also taken from the alloy ladle, from the ladle when the two metals were mixed, and drillings from the first, middle and last beds of pigs. In addition the analysis was checked by the customer. On weighing all up it was found the cast and runners weighed 12 tons 10 hundredweights, and as 3 tons were taken in the alloy ladle this left 9 tons 10 hundredweights for the air furnace alone. The air furnace and cupola metal data are given in Table 2.

All the variations are easily within analytical error, except manganese, which is accounted for by the oxidized state of the furnace metal. It might be thought the easiest way to settle this question would be to take a test from the ladle as soon as tapped, and afterwards test the casting, but those of you who take samples,

say from ingot molds, know quite well that both sulphur and phosphorus are much higher at the top end, even when a head of 6 inches has been cut off. The following is an example taken from the body of a roll, where any floating material you would take for granted had passed up into the head, yet the manganese was 0.49 per cent top and bottom; the sulphur was 0.134 per cent at the bottom, 0.151 per cent at the top; while the phosphorus was 0.225 per cent at the bottom and 0.275 per cent at the top. These results have been confirmed by the investigations of Walter, Emmel, Rhein, and lately in a paper by Schumacher, who states that the author found "no reduction of sulphur worth mentioning by increasing the manganese content under cupola conditions."

Form of Sulphur in Iron

The following statements are open to serious criticism, but

Table 2

	Total Carbon per cent	Silicon per cent	Manganese per cent	Sulphur per cent		Tons	
Air Furnace	1.820	0.080	0.075	0.145	×	9.5	÷ 12.5 Tons
Cupola	2.920	4.250	9.400	0.033	×	3.0	
Calculated	2.069	1.081	2.313	0.118			
Actual	1.960	1.120	2.070	0.115			
Difference	0.109 loss	0.039 gain	0.243 loss	0.003 loss			

in view of the increasing use of "structural composition" and the deductions drawn from it, only good can come from a clear settlement. It is invariably taken for granted if there is an excess of over 1.73 per cent manganese to 1 of sulphur, that the whole of the sulphur is in the manganese sulphide condition, and that the remaining manganese would unite with the carbon and therefore be a hardener to that extent. There is no *quantitative* proof of these statements, either chemically or microscopically, within the range of ordinary cupola cast iron with its time and temperature limits. While etching of specimens with certain reagents or heat tinting will give certain colors, which are regarded as either FeS or MnS, these areas are so irregular that it is quite impossible to arrive at any correct figure from measuring the surface content.

The whole question is best summed up by Röhl and Law. The former states "There are practically no investigations available for the purpose of deciding whether the sulphur is combined with the iron or the manganese. It is possible that yellowish brown ferrous sulphide and dove gray manganese are spoken of. This is true in so far as ferrous sulphide in fairly large flakes generally shows a yellowish brown color, while larger enclosures of manganese sulphide appear bluish gray in incident light. It must, however, be stated that it may often be difficult to a fairly trained eye to draw conclusions from the fallow color." Law states "The sulphides occurring in steels vary very much in composition and color. In some cases it is so pale in color that it is difficult to photograph, whereas in others it is so dark that it may easily be mistaken for manganese silicate." If it is so difficult to identify the various sulphides in steel, how about the complex cast iron with its fairly large amounts of other elements.

So far as the author knows, iron sulphide is seldom seen in cast iron. Even then some of the specimens put forward have not been FeS at all, the brownish blobs being due to dirty specimens not clear of the etching material, which sweats out afterwards. Has too much been taken for granted that because certain patches of MnS have been identified in a sample and no FeS located the whole of the sulphur is in the MnS condition? Most recent investigations tend to the belief that a mixed sulphide is usually found in ordinary foundry iron, whether Röhl's compound or not. Acceptance of the latter view would explain the influence of small amounts of manganese in cupola metal, for not only would it reduce the manganese by less than one-half to counteract the influence of sulphur, but its low melting point of 1365 degrees Cent. is well within cupola temperatures.

Influence of Sulphur and Manganese on Structure

Coming now to the influence of sulphur and manganese on structure as proved by the chill test, sulphur we know is a hardener and increases the chill. In conjunction with phosphorus it tends to give a hard face and a clearly defined chill. Manganese, on the other hand, up to the amount used in American and

British practice, tends to reduce the chill and gives a more mingled background.

The typical analyses of Table 3 will be used for what follows. These represent rolls, all of which are of 20-inch or 21-inch diameters, so that mass action will be the same. They were all suitable for the work required, which was from tinplate to cold rolling, and each gave good service. The depth of chill of the standard test is given (but these were cooled normally). The depth of chill on the rough roll is shown, and the difference between these two is stated as loss in the next to the last column, while the ratio of manganese to sulphur is given in the last column.

That some reaction takes place between the time the metal is tapped and the solidifying of a medium roll, is certain. There is little doubt this is due to the proportion of manganese to sulphur, other things being equal. It must also be noted that in no case except the last is the manganese below the atomic ratio.

Table 3

TYPICAL ANALYSIS OF CHILL ROLLS OF 20 AND 21 INCH DIAMETER

T.C. per cent	Si. per cent	Mn. per cent	S. per cent	P. per cent	Chill test Depth in inches	Roll chill Depth in inches	Loss Depth of chill in inches	Ratio Mn to S
3.06	0.58	0.31	0.104	0.266	2	7/8	1 1/8	3.0 to 1
3.10	0.51	0.38	0.107	0.46	2	3/4	1 1/4	3.5 to 1
2.91	0.80	0.38	0.110	0.43	1 5/8	5/8	1	3.5 to 1
3.14	0.80	0.29	0.112	0.50	1 3/8	7/8	1/2	2.6 to 1
3.26	0.66	0.28	0.164	0.51	1 5/8	1 1/4	3/8	1.71 to 1
3.34	0.70	0.31	0.198	0.53	1 1/2	1 1/4	1/4	1.6 to 1

While it is true that silicon, with other elements constant, is the controlling factor for depth of chill, it is equally certain this element is not the cause for loss of chill between the test piece and the cold roll. If so, the last analysis with its higher carbon and silicon should have lost more than the first. Although casting temperature does play a part, of which No. 2 and No. 3 of Table 3 may be examples, it is not a dominating feature. A definite casting temperature is aimed at, and is so near that given the right composition it does not show more than 1/4-inch difference. It was suggested by a member of the staff that much of the loss might be due to the fact that the test piece rested on the

chill till cold, while the roll contracted away from the round chill in about two minutes. To try this out an angle plate was cast 3 feet 0 inch long by 12 inches by 12 inches inside, the metal being 2½-inches thick. This was laid in the sand and a 12-inch square block, 3 feet 6 inches long, molded in dry sand. The angle plate formed the bottom and one side, and the mold was blacked and dried. A block was cast with each of the rolls of the compositions shown in Table 4. The first roll was 22 inches diameter, while the second was 24 inches diameter by 108 inches on the barrel.

When the blocks were broken the depth of chill approximated to the depth found on the corresponding roll, even on the vertical side where it was expected to be less.

Table 4

	Roll No. 1	12-inch Block	Roll No. 2	12-inch Block
Total Carbon, per cent	3.06	2.96	3.24	3.16
Combined Carbon, per cent	....	0.55	....	1.37
Silicon, per cent	0.50	....	0.83	....
Manganese, per cent	0.42	0.42	0.24	0.27
Sulphur, per cent	0.093	0.089	0.161	0.164
Phosphorus, per cent	0.45	....	0.50	....
Chill Test, depth in inches	2⅛	2⅛	1⅜	1⅜
Roll, depth of chill in inches	⅞	¾	⅞	⅞
Loss, depth of chill in inches	1¼	1⅜	½	½
Ratio	4 : 1	4 : 1	1.5 : 1	1.5 : 1

Through the courtesy of Mr. J. G. Pearce, director of the British Cast Iron Research Association, it is possible to show microphotographs taken at intervals from the chilled edge across the sections of the two blocks. These are shown in Figs. 2 to 12. The comments of Mr. J. E. Fletcher, consultant of the B. C. I. R. Association, who examined the specimens under the microscope, are appended as foot note (3).

Views Accounting for Differences in Loss of Depth of Chill Between Test Pieces and Rolls

There are at least three views held by various workers which might account for the difference in loss between the test piece and the roll.

The assumption of Wüst and Miny that manganese has a favorable effect on the formation of graphite because, owing to

FIG. 2

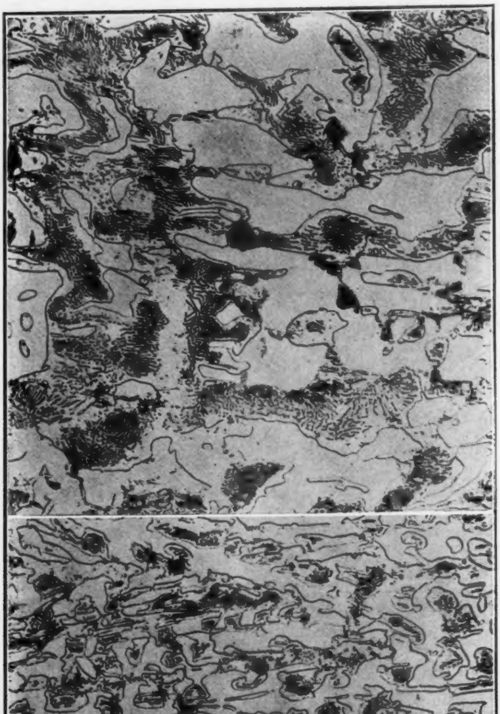

FIG. 3

FIG. 2—FIRST CHILLED BLOCK—CHILLED EDGE—PICRIC ACID ETCH—X20
FIG. 3—FIRST CHILLED BLOCK—⅞" FROM EDGE—PICRIC ACID ETCH—X200

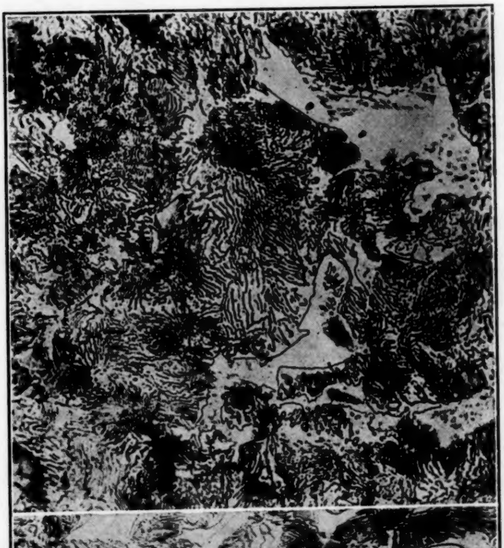

FIG. 4 FIG. 5

FIG. 4—FIRST CHILLED BLOCK—1⅛" FROM EDGE—PICRIC ACID ETCH—X200
FIG. 5—FIRST CHILLED BLOCK—GRAY AREA—PICRIC ACID ETCH—X200

FIG. 6 FIG. 7

FIG. 6—SECOND CHILLED BLOCK—CHILLED EDGE—PICRIC ACID ETCH—X200
FIG. 7—SECOND CHILLED BLOCK—1/8" FROM EDGE—PICRIC ACID ETCH—X200

FIG. 8 FIG. 9

FIG. 8—SECOND CHILLED BLOCK—¾" FROM EDGE—PICRIC ACID ETCH—X200
FIG. 9—SECOND CHILLED BLOCK—1¼" FROM EDGE—PICRIC ACID ETCH—X200

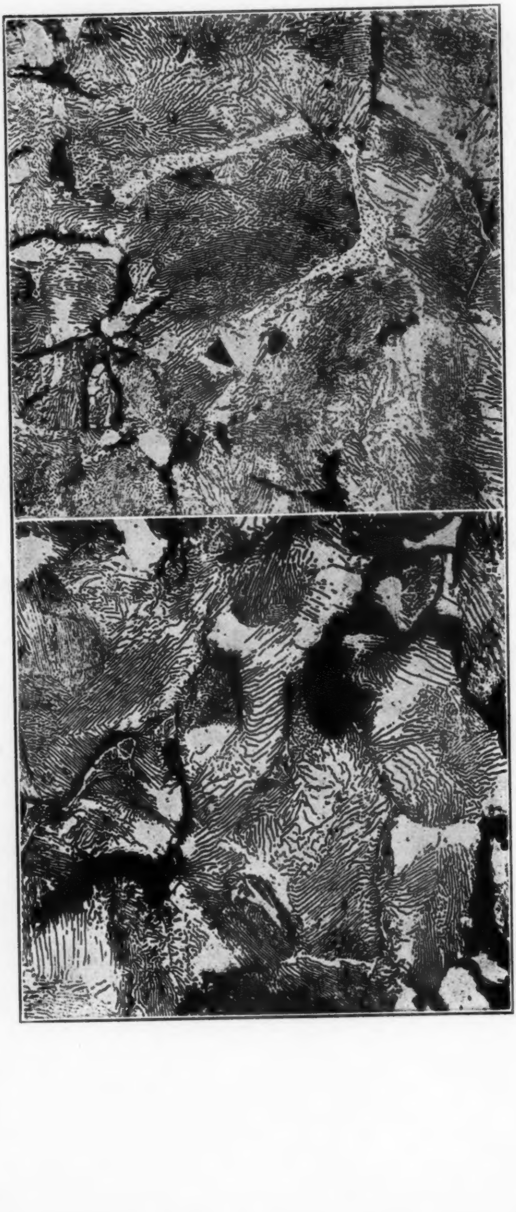

FIG. 11

FIG. 10

FIG. 10—SECOND CHILLED BLOCK—3¼" FROM EDGE—PICRIC ACID ETCH—X200
FIG. 11—SECOND CHILLED BLOCK—8" FROM EDGE—PICRIC ACID ETCH—X200

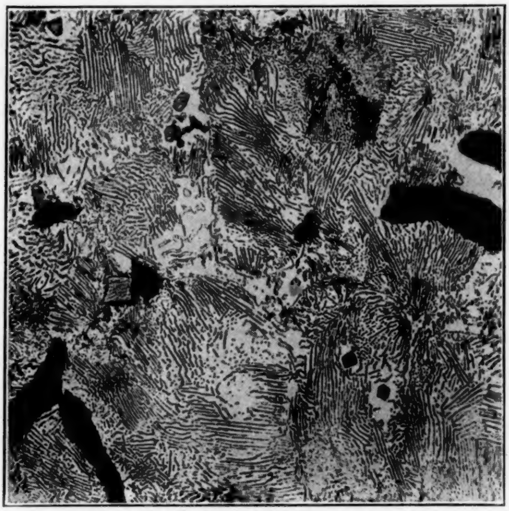

FIG. 12—SECOND CHILLED BLOCK—11½" FROM EDGE—PICRIC ACID ETCH—X200

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[a] NOTE: *Discussion of Microphotographs, Figs. 2 to 12, by J. E. Fletcher.*

Chilled Block No. 1—Figs. 2, 3, 4 and 5.

Fig. 2—Microphotograph taken from extreme edge (chilled)—magnified 200 diameters—Picric acid etch: The columnar form of crystallization—radiating inwards from the chilled surface—is seen to persist, the structure consisting of distorted Ledeburite (4.3 per cent carbon eutectic) and austenite. The C-Fe eutectic occupied most of the area primarily but has lost its characteristic honeycomb structure, only a few islands of the original austenite constituent of the eutectic remaining. Hence only the cementite of the original eutectic remains, enclosing areas of austenite which in many places are changing to pearlite. These austenite areas are the distorted portions of the first crystallites (dendrites) to solidify. They have grown by the addition of the austenite which left the Ledeburite soon after its solidification. The rate of freezing has been too great for these austenite grains to pearlitize to any considerable extent. The low silicon content has been largely responsible for this and only in scattered spots has the pearlite commenced to graphitize. It is interesting to note that at these graphite spots, or adjacent to them, small specks of sulphide—a darkened dove tint suggestive of manganese sulphide—are found. There is little trace of the phosphide eutectic in the areas next to the surface—it appears to have been squeezed into the portions in the rear of the chilled zone. Where it can be traced the phosphide eutectic is near to the spots of graphite and sulphide. The fineness of the structure next to the chilled surface in this microphotograph should be noted.

Fig. 3—Microphotograph taken ⅞ of an inch from chilled face of block, magnified 200 diameters: The greatly increased grain size is evident but the same character of structure as in No. 2 persists. There is more pearlitizing of the austenitic areas enclosed within the now coarse cementite skeleton. The still occasional graphite nodules are larger than in No. 2 and the sulphide areas (tint as before suggestive of MnS) are larger and of the angular form associated with MnS. In some areas the sulphide occurs within the pearlite and, during the polishing of the specimen the sulphide spot has been partly rubbed away, revealing the striations of the pearlite underneath the sulphide. The exceptionally dark tint of some of the sulphide spots suggests alloyed mixtures of the two sulphides FeS and MnS, but these spots have the characteristic angular shape which has generally been considered typical of MnS.

the formation of MnS, sulphur is extracted from the melts before the graphite begins to form, was the view the writer held at first. That point has been dealt with above. Also if you remember that the metal is often held in the air furnace at fairly high temperatures for quite four hours, while manganese and carbon determinations are made, and often to rectify the chill, it would be expected that a state of equilibrium would have been attained before the metal was tapped into the ladle, both chill test and roll being cast from the same ladle. The loss, as far as we can analyze, does not arise from any considerable loss of sulphur between the test piece and the roll.

The second view, that the small loss in the roll with the high sulphur and low manganese is due to the stabilizing effect of the sulphur on the carbide—is sound. In this connection the excellent paper by Piwowarsky gives some illuminating examples. His cooling and other curves are to be found in Figs. 13 to 17. The 50 degrees Cent. per minute fall in temperature is

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Small globular beads of bronze or gold coloration occur very occasionally in such irons but only traces occur in this block. They have been considered to be either FeS or the FeS-MnS eutectic referred to by Rohl and others. The bronze tint noticeable in stray areas in the pearlite and which blurs the lamellar form wherever it occurs suggests a possible colloidal FeS condition—as described by F. C. H. Lantsberry. It appears to occur always near to the boundary of the pearlite grains. The microphotographs do not bring this condition out very clearly but it can often be seen through the microscope at higher powers than 200 magnification.

Fig. 4—Microphotograph taken 1¼ inches from chilled face of block—magnified 200 diameters: The grain growth is still more pronounced, the cementite now enclosing larger areas of austenite which are nearly all pearlized. Both flake and nodular graphite are present in considerable quantity, the structure being now typical of a mottled fracture in the metal. The phosphorus eutectic in this, as in Nos. 2 and 3, is difficult to trace in the photographs but is found along the boundaries of the free cementite skeleton—often near to where the sulphides are visible. The actual chill finishes between the locations of the microphotographs 2 and 3. The latter shows that pearlitization of the structure is proceeding rapidly, pearlite occupying more than half the area.

Fig. 5—Microphotograph taken from gray portion behind chill—magnified 200 diameters: Here the metal is pearlitic in character. It is noteworthy that much of the graphite is in nodular form and can be generally traced to the now enlarged pearlite grain boundaries. The last remains of the free cementite skeleton (part of the decomposed Ledeburite) are also visible along the pearlite grain boundaries, where they are found associated with the phosphide eutectic. The migration of the phosphide eutectic and of the sulphide or sulphides is seen in the gray areas immediately behind the chill portion, the areas of the phosphide eutectic and sulphides being individually larger than in the white or chill areas. This migration would probably occur when the austenite dendrites were still surrounded by the eutectic constituents. The rapid growth of the dendrites nearest the chill would force the eutectiferous material—in which some of the sulphide would be floating—towards the more slowly cooling metal in the rear of the chill zone. The metal being strongly hypo-eutectic (containing about 70 per cent eutectic and 30 per cent silico-iron, etc.), the pearlitic structure where fully developed is surrounded by ferrite and where not fully developed by austenite. In the neighborhood of the graphite flakes or nodules the pearlite grains are bounded by ferrite and, wherever any free cementite remains the pearlite grains are bounded by austenite and here the pearlite is not fully developed. The low silicon content, by hindering graphitization, enables the austenitic character of rapidly cooled hypo-eutectic cast iron to persist.

supposed to represent the normal fall in thin castings, while the 10 degrees Cent. per minute is the ratio of fall in temperature when medium castings are in question. Unfortunately no actual thickness is mentioned. Figs. 14 and 15 are eutectic mixtures, while Figs. 16 and 17 represent the hypo-eutectic irons used. The four analyses for each are given at the side, the manganese in all cases being 0.26 per cent, while the phosphorus was 0.038 per cent, and the sulphur was increased as shown. The summary given of the results of 70 melts was as follows:

1. That in low-manganese cast irons the effect of sulphur on the formation of carbides is the more intense and discontinuous—
   - (a) the lower the total carbon and silicon
   - (b) the greater the rate of solidification and cooling of the casting. (Wall thickness.)

Chilled Block No. 2—Figs. 6, 7, 8, 9, 10, 11 and 12.

Fig. 6—Microphotograph taken from extreme edges (chilled), magnified 200 diameters: This has similar characteristics to those of microphotograph of Fig. 2 of Block 1. The higher total carbon content has resulted in a finer crystalline structure but there are more numerous specks of graphite and sulphide.

Fig. 7—Microphotograph taken ⅛ of an inch from the edge—magnified 200 diameters: Grain growth is evident. Pearlitization has almost reached the extent shown in microphotograph of Fig. 3 of Block 1. Occasional star shaped flakes of graphite occur in this zone and indicate that the boundary of the chill zone is being approached. The sulphide specks are still small and the areas of phosphide eutectic—attached to the free cementite skeleton—are small and ill defined.

Fig. 8—Microphotograph taken from point ¾ of an inch from edge—magnified 200 diameters: Grain growth continuing. More graphitization and formation of pearlite. Size of sulphide specks increasing. More phosphide eutectic visible and in larger individual areas. Graphite is of flake type and pearlite is of rather coarser type than that in Block 1. There are occasional rounded globules of bronze tint suggesting presence of FeS or MnS-FeS alloy. One is seen near the center of the microphotograph. Most of the sulphide specks are of the angular form representative of MnS.

Fig. 9—Microphotograph taken 1¼ inches from edge—magnified 200 diameters: Pearlitization increasing and so is the graphite—in flake form. Structure is typical of mottled roll metal. Sulphide spots are still larger than in microphotograph of Fig. 4 and there are odd spots of the bronze tinted constituent—always rounded and sometimes drawn out into the form of elongated pears—suggesting plasticity at time of solidification.

Figs. 10, 11 and 12 taken from interior gray portions—magnified 200 diameters: Phosphide eutectic bounds many of the pearlite grains and there is evidence of much ferrite where graphitization has been greatest (Fig. 10). Size of sulphide spots tending to increase (Fig. 12), Phosphide eutectic occurs in grain borders and in greater bulk. (See Fig. 11.) It has been noted that the dove colored sulphide inclusions often show a dappled or lamellar appearance at higher magnification—suggestive of eutectic structure. In some cases the sulphide inclusions are of dark brown or brown-black tint and are then of angular shape and at higher powers show the dappled or lamellar internal structure above described. All these microphotographs show typical pearlitic grains.

2. That it is to the producers' interest, when making low-manganese iron (below 0.3 per cent to 0.4 per cent) to aim at a sulphur content of less than 0.08 per cent to 0.1 per cent in the finished material. An increase of manganese to at least 0.7 per cent offers, however, great advantages, because even in low-silicon, low-carbon (high-quality) cast iron, a sulphur content of up to 0.15 per cent must be regarded as harmless.

A point worth noting in connection with the graphs of Figs. 14 to 17 is that with manganese constant at 0.26 per cent and

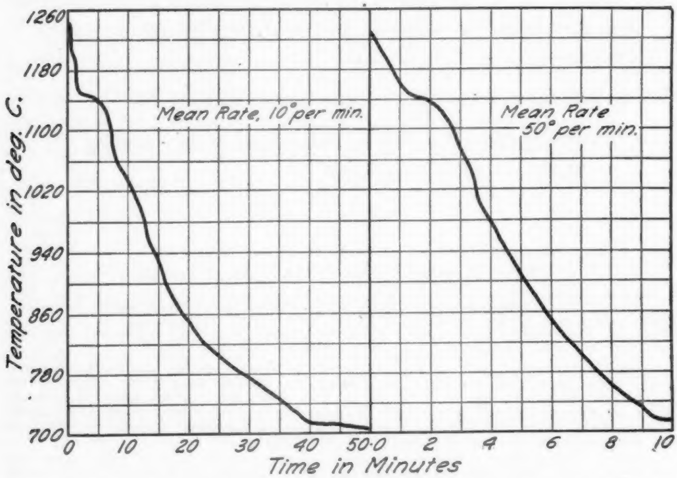

FIG. 13—COOLING CURVES WITH MEAN COOLING SPEEDS OF 50° PER MINUTE (RIGHT) AND 10° PER MINUTE (LEFT)

phosphorus at 0.038 per cent, total carbon of 3.68 per cent and silicon of 2.76 per cent neutralize the carbide forming tendency of 0.736 per cent sulphur, the combined carbon only being 0.58 per cent. Also if the silicon is lowered to 1.86 per cent, this, with carbon at 3.64 per cent, can still keep the combined carbon down to 1 per cent with sulphur at 0.296 per cent. The above two examples were cooled at 10 degrees Cent. per minute. Even when cooled five times as quickly, viz.—50 degrees Cent. per minute, it would appear that 3.68 per cent total carbon and 2.76

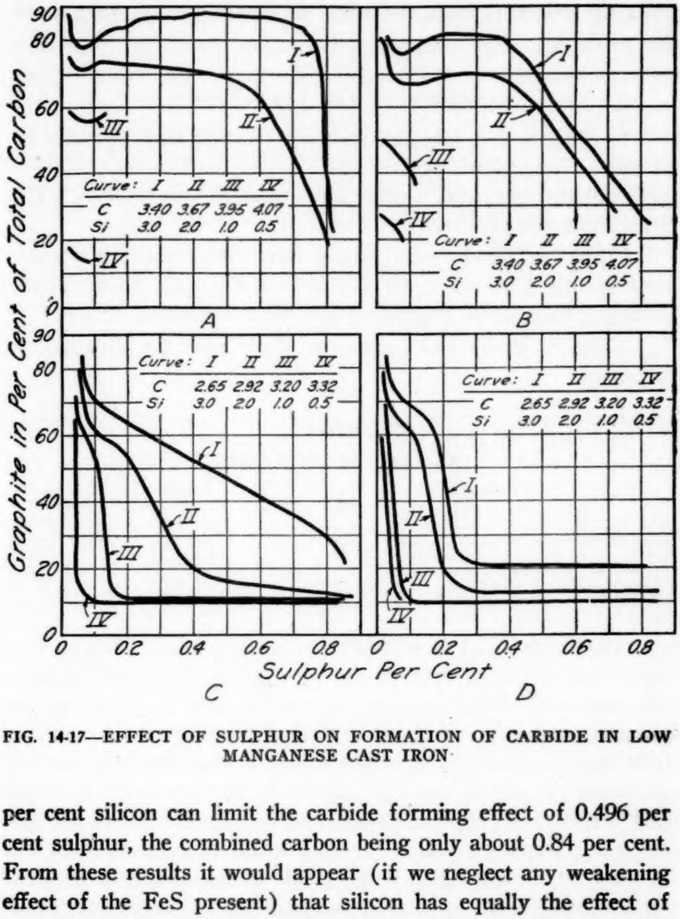

FIG. 14-17—EFFECT OF SULPHUR ON FORMATION OF CARBIDE IN LOW MANGANESE CAST IRON

per cent silicon can limit the carbide forming effect of 0.496 per cent sulphur, the combined carbon being only about 0.84 per cent. From these results it would appear (if we neglect any weakening effect of the FeS present) that silicon has equally the effect of neutralizing the carbide forming effect of sulphur that is attributed to manganese. This is in line with Coe's work in 1912. He states "the influence of sulphur on the condition of the carbon varies according to the percentage of silicon present; when the silicon is low (about 1 per cent) very small additions of sulphur will throw the greater part of the carbon into the combined form;

when the silicon is high, the effect of the sulphur is very much less marked."

Experiment to Test Coe's Theory

In order to test this out, four test bars 1.2-inch diameter by 14 inches long were cast vertically in dry sand molds. These were tested, transverse, tensile and deflection being taken. The composition was as given in Table 5.

While the tensile tests results were fairly good, the transverse results were not equal to those of metal of lower sulphur or higher manganese containing the same combined carbon.

Table 6 shows the results of Coe's and the present experiments.

Table 5

ANALYSIS OF TEST BARS

	Two bars K per cent	Two bars D per cent
Total Carbon	3.36	3.52
Combined Carbon	0.98	1.05
Silicon	3.04	2.80
Manganese	0.55	0.35
Sulphur	0.34	0.285
Phosphorus	0.038	0.35

The author had two objects in making these experiments; first, confirmation of Piwowarsky's results, secondly, to determine what effect the large sulphur content of these bars had on the physical properties of the iron. Coe's results would point to little loss of strength or deflection even when the sulphur was ten times the atomic ratio of sulphur to manganese (S 0.18 per cent Mn 0.03 per cent). Unfortunately owing to the recent coal dispute it was not possible for us to make more than three sets of bars, one set of which K(B) Table 6 was useless because the ratio of manganese to sulphur was too high (S 0.197 per cent—Mn 0.55 per cent). The K bars results lend some strength to Coe's contention, but the results of D bars do not. The whole results of the D bars are so irregular (a combined carbon of 1.05 per cent, yet with a Shore scleroscope hardness of 34 and long flaky graphite) that the experiment must be carried out a number of times before any conclusions can be drawn.

It was thought it would add to the interest if microphotographs of the cross section of these bars were added. These microphotographs are given as Figs. 18 to 30 inclusive. In all five sets of samples were sent out, and in no case was FeS identified as a separate identity. This is in accordance with Hurst's interpretation that FeS in the quantities present in cast iron cannot be separately identified because it exists in solid solution in the iron. It is probable that an eutectoid containing FeS exists but in high carbon alloys such as cast iron this eutectoid has never been identified and would be extremely difficult to identify if it did exist. The question of the formation of MnS in these bars deserves your consideration. The base of the material was

Table 6

COMPARISON OF TEST RESULTS OF COE'S EXPERIMENTS AND THOSE OF SHAW, TO SHOW INFLUENCE OF SULPHUR ON CONDITION OF CARBON WITH VARYING PER CENT OF SILICON

	Experiments					
	Coe	Coe	Coe	K (A)	K (B)	D
Total Carbon, per cent	2.94	2.70	2.90	3.36	....	3.52
Graphitic Carbon, per cent	1.84	1.57	1.57	2.38	....	2.47
Combined Carbon, per cent	1.06	1.13	1.33	0.98	0.35	1.05
Silicon, per cent	2.24	2.37	1.23	3.04	....	2.80
Sulphur, per cent	0.104	0.180	0.204	0.34	0.197	0.285
Manganese, per cent	0.03	0.03	0.325	0.55	0.55	0.35
Phosphorus, per cent	0.01	0.01	0.01	0.038	0.035	0.038
Transverse strength of 12 × 1 × 1 inch bar in pounds	3,326	3,998	3,057	2,867	4,301	1,702
Deflection, in inches	0.114	0.150	0.097	0.18	0.20	0.12
Tensile strength, pounds per square inch	29,210	34,272	28,246	25,760	35,840	20,428
Shore Scleroscope, Hardness Number	45	43	53	42	..	34

a hematite with 0.07 per cent S. In Mr. Dickinson's case a pot furnace was used and the highest temperature attained was 1300 degrees Cent., yet these are large areas where so-called MnS is in evidence. Two theories are advanced to cover this point; first, that chemical reactions take place independently of temperature or melting point, of which case hardening is an example, and secondly, that the areas of supposed MnS are mixed sulphides with much lower melting points than the 1620 degrees Cent. of MnS.

With these microphotographs are included the actual findings of Mr. J. E. Fletcher and Mr. Glen Primrose. Mr. Fletcher's comments are given as footnote (4) and those of Mr. Primrose as foot note (5).

Discussion of Third View of Loss of Chill Between Test Bars and Rolls

This brings us to the third view regarding the cause of loss of chill between the test and the roll, viz.—that manganese, under certain conditions acts as a softener, not only by its action on the sulphur, but by its direct graphitizing effect on the carbon.

It may be taken for granted that silicon and manganese are similar in their neutralizing of the carbide forming effect of sulphur. Both are hardeners of cast iron by their direct action, and both elements have a softening effect on cast iron due to their indirect action on the carbon.

Outerbridge, Jr., suggests that the softening effect of manganese is lost when high carbon, high silicon (with its low sulphur) are present in the material. He states it often leads to hard spots. Coe is in agreement with this idea, "It appears that a quantity of manganese as low as 0.18 per cent (with no sulphur present) is able to produce a great change in the composition of the iron; more than about 0.5 per cent manganese tends to retain more carbon in the combined form." Now all these statements, while true for the conditions worked under, do not hold good

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[*] NOTE: *Discussion by J. E. Fletcher of Microphotographs of Bars K and D, Figs. 18 to 25.*

The structures are quite typical of the two metals when cast under such conditions as would yield pearlite throughout the bar sections. The size of the graphite flakes and of the pearlite grains varies across the bar section in each case, the smaller grains being, of course, associated with more rapid cooling. Part of the metal making first contact with the mold surface and thereby cooled has obviously been swept into the interior portions of the section and has cooled there, thus causing the lack of uniformity seen in the unetched microphotographs of Figs. 19 and 23. The metal in bars K was almost eutectic and has yielded nearly perfect pearlite, very little free ferrite being seen.

The presence of the sulphides is clearly responsible for this fact, the pearlite being intermingled with free cementite in local areas. The higher sulphur content in bars K is seen in the etched microphotographs of Figs. 24 and 25 (200 diameters) when compared with microphotographs of Figs. 20 and 21 (bars D). The sulphide in the K bars is in larger individual areas of typical MnS shape than in bars D.

It would be expected—according to generally accepted ideas—that FeS areas in the microphotographs would appear. There is some evidence that free FeS is present in both metals, the golden or bronze tinted crystals being found surrounding or sandwiched in between the dove colored MnS areas. But this phenomenon was only observed in a few localities throughout the entire polished area and, unless the FeS is distributed in colloidal precipitations more generally, there is insufficient evidence to prove that FeS commonly exists as free crystals in cast irons of the D analysis.

The writer observed the golden tinted globules in specimens from the chill block 2 where the Mn content is 0.27 per cent and the S content 0.164 (Mn/S ratio 1.65) and in the metal bar D where the Mn content is 0.35 per cent and the S con-

FIG. 19

FIG. 18

FIG. 18—D BAR—HIGH SULPHUR IRON—UNETCHED—X50 (FLETCHER)
FIG. 19—D BAR—HIGH SULPHUR IRON—UNETCHED—X50 (FLETCHER)

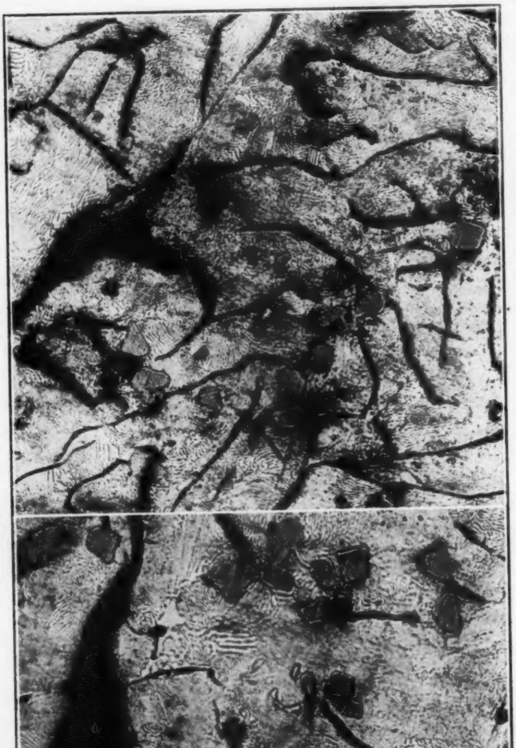


FIG. 20

FIG. 21

FIG. 20—D BAR—HIGH SULPHUR IRON—PICRIC ACID ETCH—X200 (FLETCHER)
FIG. 21—D BAR—HIGH SULPHUR IRON—PICRIC ACID ETCH—X200 (FLETCHER)

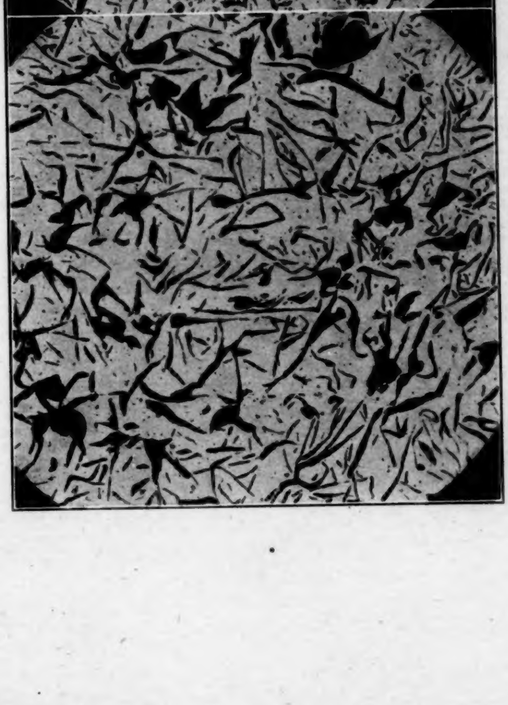


FIG. 22

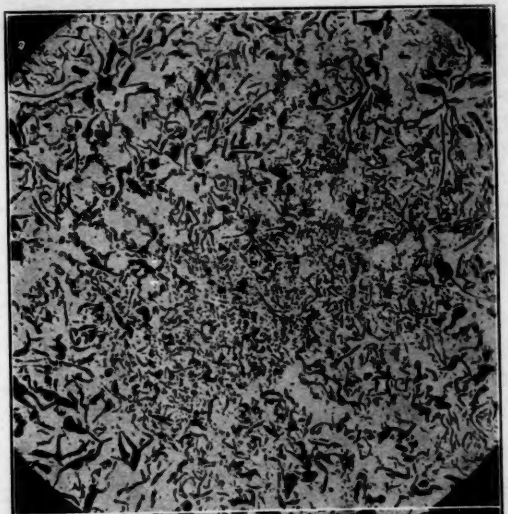


FIG. 23

FIG. 22—K BAR—HIGH SULPHUR IRON—UNETCHED—X50 (FLETCHER)
FIG. 23—K BAR—HIGH SULPHUR IRON—UNETCHED—X50 (FLETCHER)

FIG. 24 FIG. 25

FIG. 24—K BAR—HIGH SULPHUR IRON—PICRIC ACID ETCH—X200 (FLETCHER)
FIG. 25—K BAR—HIGH SULPHUR IRON—PICRIC ACID ETCH—X200 (FLETCHER)

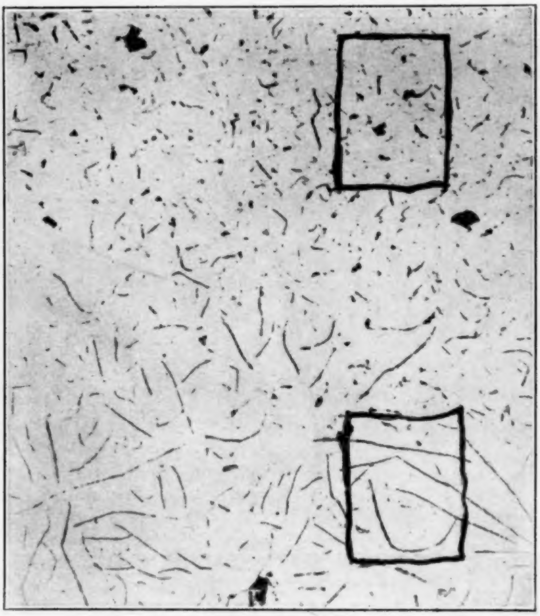


FIG. 26—D BAR—HIGH SULPHUR IRON—UNETCHED—X100 (PRIMROSE)

tent 0.285 (Mn/S ratio 1.23). Only traces could be seen in the chill block 1 and bar K. If these bronze tinted globules are FeS then the same constituent, which has been observed in white fractured hematite iron (Mn 0.15 per cent S 0.35 per cent for example) as used for white heart malleable castings would appear to favor the theory that when there is insufficient Mn to meet MnS needs the remainder of the S is present in the form of FeS. But there is always the possibility that the two sulphides may be present in a compound form or as a eutectic. We have no certain information that such compounds or mixtures of the two sulphides show the golden tint observed in malleable casting structures and in the chill block 2 and bar D.

The combined carbon contents in the two bars K and D are in excess of true pearlite requirements and, were the sulphur content lower, the combined carbon content in normally cast metal would be generally below 0.7 per cent (with S below 0.10 per cent). Hence the conclusion that sulphur in the region of 0.3 per cent has been responsible for the high combined carbon content in the bars K and D.

[8] NOTE: *Discussion by Glen Primrose regarding Bars D and K, Figs. 26 to 30.*

Figs. 26, 27, 28—D Bar: The main thing to note is the great segregation of graphite in Fig. 26. This is near the core and shows the effect of the inverse chill due to sulphur. The other two microphotographs show the big graphite patches near the top and the small graphite lower down.

K Bar: There is a much more uniform distribution of graphite for size of flake and the unetched microphotograph (Fig. 29) at 100 diameters indicates the small size of this, also the very striking nest of sulphides present. There are many patches we could see at about 100 diameters where no sulphide shows at all. The arrow head is clearly shown in this print and it is seen how the sulphides have globularized. This is typical of MnS and there is no trace of FeS that we could see anywhere in a long search. These were etched with picric acid, so as to make the biggest difference possible between MnS and FeS if any.

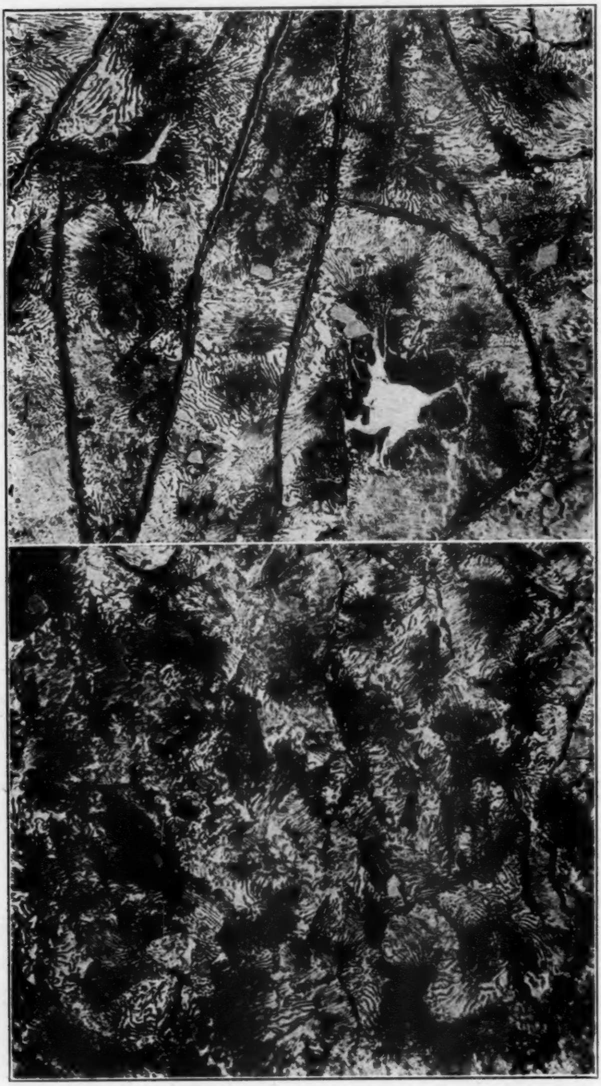


FIG. 27 FIG. 28

FIG. 27—D BAR—HIGH SULPHUR IRON—ALCOHOL ETCH—X100 (PRIMROSE)

FIG. 28—D BAR—HIGH SULPHUR IRON—ALCOHOL ETCH—X100

FIG. 30

FIG. 29

FIG. 29—K BAR—HIGH SULPHUR IRON—UNETCHED—X100 (PRIMROSE)
FIG. 30—K BAR—HIGH SULPHUR IRON—ETCHED—X500 (PRIMROSE)

for different conditions. For instance, earlier in the same paper Coe states when using a Blaenavon hematite and casting ¾-inch square bars from it, "It will be seen from the analyses that the addition of 2 per cent manganese to such an iron produces an inappreciable chemical effect, in fact, it appears that with 2.65 per cent manganese there is a softening action owing to a decreased percentage of combined carbon." Low carbon, low silicon, and high sulphur would all demand higher manganese to obtain the same softening effect on irons of contrary composition. This factor may perhaps reconcile some of the divergent views held on this question.

What proofs can be offered? Outerbridge, Jr., in a paper[6] before this association, found that the addition of roughly 0.14 per cent manganese to a ladle of metal reduced the chill. The combined carbon was reduced to about one-half of that in the receiving ladle. "Manganese," he mentioned, "is commonly supposed to exert a hardening effect on cast iron, but experience has taught me to regard this as another mistaken notion." The reaction mentioned above is regarded in some quarters as due to deoxidation, but when you remember that the car wheel specification calls for a manganese content of not less than 3 to 1 of sulphur in the finished product, it would be thought there was enough surplus manganese present to do all deoxidation needed in the cupola or at least in the large receiving ladle, long before this small addition of manganese was made in the 600 pound ladle. If you will consider this as an addition of softening material the result is clear at once.

Coe's experiments were conducted under laboratory conditions, so oxidation would be taken care of. As in his gray iron material sulphur was below 0.03 per cent and below 0.01 per cent in his phosphoric iron, the question of the effect on the sulphur would not enter into the results to any extent. Two of his results have been quoted. During the preparation of a paper on "Silicon in Cast Iron" by Hague and Turner, the authors found that an arrest point, previously noted in a prior investigation, had disappeared while using their present iron. The only difference

[6] Outerbridge, Jr., A. E., *Manganese and Silicon in the Foundry*, Trans. American Foundrymen's Association, vol. 20, 1911, pp. 17-34.

approximately being an 0.5 per cent manganese, it was resolved to make this addition and try the result out. It was found this reduced the combined carbon from 0.84 per cent to 0.22 per cent. The two analyses were those given in Table 7.

In Turner's words "It was seen that there is a considerable expansion corresponding to the arrest point A_3, while the temperature of this arrest is lowered from 764 degrees Cent. to 687 degrees Cent." Hague suggests a possible explanation of this expansion, that "it is caused by the separation of a second quantity of graphite, that from the saturated martensite. In view of the fact that the sulphur is only a trace it is interesting to record this direct stable graphitizing forming tendency of the manganese." He also states that "it is only in conjunction with silicon that manganese has this influence."

Table 7

	Original metal per cent	Plus 0.5 per cent Mn. per cent
Total Carbon	2.77	2.62
Graphitic Carbon	1.93	2.40
Combined Carbon	0.84	0.22
Silicon	3.06	3.00
Manganese	Nil	0.5
Sulphur	Trace	Trace
Phosphorus	Trace	Trace

Our interest was roused in this subject by noting the combined carbon content in certain rolls not widely varying in analysis, and also to the fact that a combined carbon content round the pearlitic point gave a better wearing surface. If you will turn back to the experiment carried out with the 12 inch square blocks you will find the analyses of two rolls that are fairly divergent. In so doing differences are most easily seen. The composition of roll No. 2 was aimed at because a hard face was of more importance than strength. Please note the combined carbon content and account for its difference by any other reason than the ratio of manganese to sulphur. There is little doubt in our minds that the excess manganese over that necessary to counteract the influence of the sulphur present (whether this is in the form of MnS or $Fe_3Mn_2S_5$, or simply a mixed sulphide, does not concern us for the time). With total carbon 2.96 per cent, silicon 0.5 per cent, you have a combined carbon of 0.5 per cent; yet with the higher

total carbon of 3.16 per cent and silicon of 0.83 per cent, your combined carbon is 1.37 per cent. Take twenty rolls haphazard whose composition is much nearer, ten with combined carbon below 1 per cent and ten with combined carbon over 1 per cent, the average of the first ten worked out as in the first column and the second ten averaged as column No. 2 in Table 8.

These results can be duplicated by reference to the laboratory books. They are left for your criticism and comment. That the results justify the contention, the two microphotographs (Figs. 31 and 32) taken from the centre of a 33 inch diameter roll weighing 9 tons will show.

Effect of the Ratio of Carbon to Silicon on the Structure

The effect of the ratio of carbon to silicon on structure as judged by the chill test is to be considered. The influence of both

Table 8

COMPARISON OF ANALYSIS OF ROLLS: GROUP 1 WITH COMBINED CARBON BELOW ONE PER CENT; GROUP 2, COMBINED CARBON ABOVE ONE PER CENT

	No. 1	No. 2
Total Carbon, per cent	3.01	3.167
Combined Carbon, per cent	0.81	1.32
Silicon, per cent	0.62	0.79
Manganese, per cent	0.426	0.381
Sulphur, per cent	0.128	0.162
Ratio	3.3 Mn to 1 S	2.09 Mn to 1 S

silicon and carbon has been so fully investigated by Turner, Wüst, Gontermann and others, that their effect is well known. What is to be deprecated is the attempt made to apply their conclusions, without due attention to the equally dominating factors of moderate amounts of manganese, sulphur and phosphorus in cast iron.

The use that is constantly being made of considering complex cast iron simply as a certain percentage carbon steel interspersed with free graphite, can only lead to wrong conclusions. It is not proposed to discuss this question, but to point out another factor that calls for consideration, that of the grouping together of the total carbon plus silicon content as contained in some papers. From it the ordinary man would judge that if total carbon + silicon = 5, a similar structure would be obtained if your mixture (other constituents being equal) was either total carbon 4 per

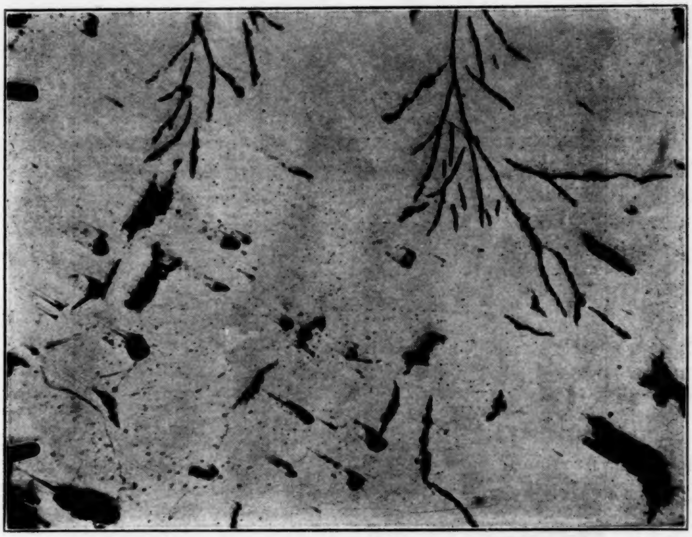


FIG. 31—33" DIAMETER ROLL 9 TONS—CENTER OF ROLL—TWO TYPES OF GRAPHITE—UNETCHED—X50 (PRIMROSE)

cent + silicon 1 per cent or total carbon 1 per cent + silicon 4 per cent. We have found, to our cost, that this is not so, and it is not till you are tied down to the fine limits imposed by chill that you appreciate it.

Thrasher, in a malleable paper[7], put forward the following ratio—that "four points of carbon are equal in effect to three points of silicon, when the silicon in the mixture is over 0.7 per cent; and that below this silicon content, two points of carbon are equivalent to one point of silicon in their effect on the structure of the iron" (Fig. 33). Our experience over several years supports these figures, and you will find further confirmation if you refer to Fig. 5 of Lowry's paper[8] before this association in 1924. Taking the curve of the ½ inch chill, the lower end shows

[7] Foundry, December, 1915.
[8] Lowry, E. J., *The Effect of Chill on Cast Iron*, Trans. American Foundrymen's Association, vol. 32, Part 1, p. 551, 1925.

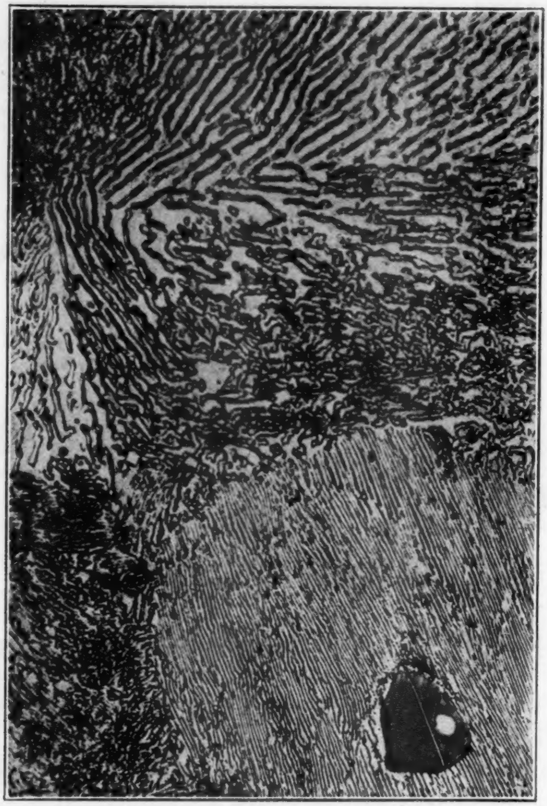


FIG. 32—33" DIAMETER ROLL, 9 TONS—CENTER OF ROLL—VARIOUSLY ORIENTED PEARLITE AND SULPHIDE—ETCHED—X500 (PRIMROSE)

3.67 per cent total carbon + 0.4 per cent silicon, the upper end 3.04 per cent total carbon + 0.75 per cent silicon, the difference being as 35 is to 63, or about twice. The ¼ inch chill curve with its higher silicon works out at 51 to 68, or nearly again Thrasher's figure of four points carbon equivalent to three points silicon.

It may be thought that a chill test, while needful for chilled work, does not find a place in ordinary gray iron practice. For a

number of years we have used nothing else, except a direct impact test. While we cast test bars for our customers every week, there are none cast for ourselves to check this work, yet we have only had two failures during the past two years, and both these would pass the A. F. A. specification. We quite appreciate the value of test bars, but unfortunately their results are not known till after your mold is cast. By using the chill test we have a good idea of the ultimate structure of our metal before casting. For instance we know, that quite irrespective of composition, if the

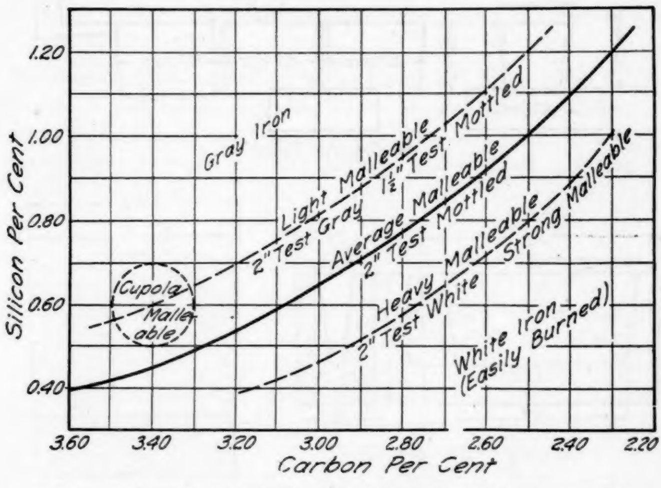


FIG. 33—DIAGRAM SHOWING LINES OF EQUAL NATURAL CHILL (THRASHER'S DIAGRAM)

chill test shows ⅛ inch to ¼ inch on the 1¼ inch chill test, castings ¾ inch to 1 inch thick will machine readily, and the 1.2 inch diameter bar will easily pass the specification and yield at least 10 tons per square inch tensile. For castings averaging 1½ inch thick a test of ½ inch to ¾ inch deep is required, and for cylinders 3 inch thick a chill test of 1½ inch to 1¾ inch is required. When you are asked for the higher tests, say 14 to 18 tons tensile, composition is vital and demands low carbon, silicon and phosphorus. For silicons 2 per cent and over, the 1¼ inch thick test is use-

less, the depth of chill being only about 1/16 inch or less in all cases, so a wedge test was used. This consists of a complete chill with a taper slot 6 inches long by 1 inch at the top, to ¼ inch wide at the bottom, the depth being 2¾ inches. A sketch of this is given in Fig. 34B. To use it the chill is slightly warmed, and when your ladle is nearly full a test is cast from a pot ladle dipped into the metal. At the end of one minute the chill is turned over,

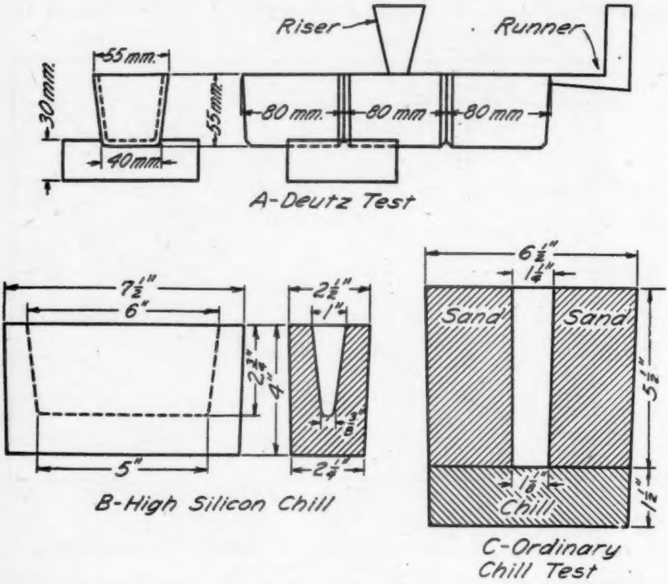


FIG. 34—CHILL TESTS—A, DEUTZ TEST—B, HIGH SILICON CHILL TEST—C, ORDINARY CHILL TEST

the tests drop out, and it is dipped into water and broken. The depth of chill is registered from the ¼ inch end. Data from this source correlated to the machining speeds in the machine shop, can soon be built up. This information can be used if ever there is doubt about the metal before the castings are run. A third test in daily use was given to the author by the courtesy of the technical director of the Deutz Gas Engine Co., Cologne. It con-

sists of a combination chill and segregation test. The test bar is divided into three pieces as shown by the notches, and a chill is placed from one end to the middle as shown in the sketch, Fig. 34A. Besides giving the depth of chill and therefore some idea of the ultimate structure by its quicker cooling, any sign of segregation is shown in the more slowly cooled half. This test is cast from the main ladle, left to cool till morning, and broken in three pieces through the notches. The centre piece is then taken into the foundry manager's office, and he can see at a glance from the depth of chill if the hardness of the metal is suitable for the job, and also if there is any tendency for segregation, which would show up at the gray end.

In conclusion the author wishes to thank Mr. Fred. Firth for permission to publish the figures, his assistants, Messrs. Green and Roxburgh, Mr. J. S. Glen Primrose and Mr. J. G. Pearce for the microphotographs, and Mr. Kayser, Mr. Fletcher and Mr. Dickinson for independent tests.

APPENDIX*

We have recently made a few more sets of high sulphur bars, making the ratio of sulphur still higher in our endeavor to test out the physical properties, and, if possible, to locate FeS in ordinary cast iron with high sulphur and low manganese. The chemical composition of the bars of the last test was as follows:

Total carbon	3.58 per cent
Combined carbon	1.08 per cent
Silicon	2.80 per cent
Manganese	0.17 per cent
Sulphur	0.342 per cent
Phosphorus	about 0.035 per cent

The test on the 1.2-inch diameter bar broken on 12-inch supports gave 2,510 pounds. The ⅞-inch diameter bar broken on 12-inch supports gave 880 pounds. These bars, made at Sheffield University, were cast at 1300 degrees Cent. The others are being cast at 1400 degrees Cent. and should give higher results if they

*Submitted by the author following presentation of paper at Detroit meeting.

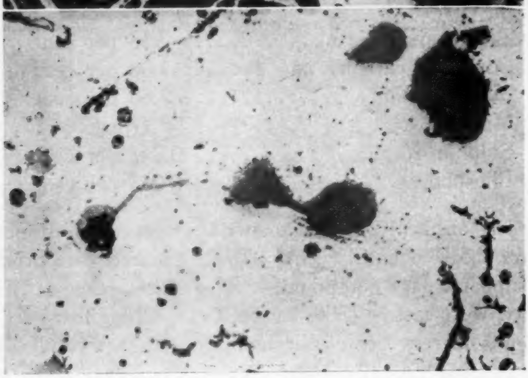


FIG. 35—MAGNIFIED 500 DIAMETERS

FIG. 36—MAGNIFIED 1,000 DIAMETERS

FIG. 37—MAGNIFIED 500 DIAMETERS

follow previous bars. Micro-photographs were prepared from ¼-inch sections cut across the 1.2 diameter and the samples were sent to five experts—Dr. Hatfield amongst them. Two of these men cannot locate FeS in this iron. Mr. Primrose and the author spent two hours searching an etched sample under a large microscope with which one has full control of the field, and can search every minute piece without resetting. We located several points that we took to be FeS and their shape and color lend strength to this conclusion. Three of these micro-photographs are shown in Figs. 35, 36 and 37.

Mr. Primrose's remarks concerning these micro-photographs are as follows:

"Micro-photograph of Fig. 35 at 500 diameters. The graphite is comparatively small. The main feature of the center of the picture is the globules of apparently pasty material which has gathered not only in the pearlike areas, but also in the cementite where the combined carbon is chiefly showing in excess of the eutectoid point. These sulphides were distinctly yellow, and in confirmation of their being FeS in this case, you will see the upper one in the middle has a long tail to it as if following an intergranular fissure. The high power (1000 diameters of micro-photograph of Fig. 36) shows the cementite ground mass in which most of the sulphide occurs, and I am inclined to attribute the dark patches in the light colored sulphide to small portions of this brittle material which have broken out in the polishing, rather than to any chance of MnS separating from the sulphide by chemical reaction. Micro-photograph, Fig. 37, shows the sulphide in another spot where there is a carbide separation, but you will note the small spots of sulphide in the surrounding pearlite areas."

Discussion

R. S. Macpherran: I would like to get Mr. Shaw's own personal opinion about the effect of sulphur. He refers to several other investigations, but in no place does he summarize his own personal ideas. I would like to know what he thinks himself about high manganese and low manganese iron.

J. Shaw: While I do not care to dogmatize about the effect of sulphur, my investigations moved me to use a medium sulphur, except in

a few cases, for two reasons. First, using a high sulphur (say 0.2 per cent) with a low manganese (say 0.3 per cent) would require raising the silicon if it were necessary to machine the medium and thin castings. The higher silicon would tend to give a large primary graphite with large flakes and therefore a weaker iron. Secondly, with a high sulphur (say 0.2 per cent), and high manganese (say 1 per cent), the sulphur would probably all be in the MnS condition and with high sulphur this constituent tends to segregate. Stead showed by trepanning sections out of a steel plate containing large amounts of MnS that pieces containing MnS broke readily, because the MnS is a weak, brittle substance and will break like a carrot. To that extent MnS weakens your casting.

J. W. BOLTON: It is evident that Mr. Shaw himself knows a great deal more about the question of sulphur than possibly—I am speaking for myself now and not for the rest of you gentlemen—than the rest of us.

I wonder if Mr. Shaw would think the method of study of fractures, microscopic study of fractures in cast iron, would not be of some benefit in furthering the research work of the British Cast Iron Research Association and of Mr. Shaw along this line? If we break a piece of cast iron you can investigate the line of fracture between the graphite flakes and the pearlite.

Now, let's digress for a moment and go to the solidification of cast iron. First you have columnar crystallization. The dendrites reach into the casting. Later the metal passes through the austenitic range and you have granulation; you have some evidence of that in irons that are thrown down through the critical range very speedily. I have noted that in this condition the austenite grains, or what would have been austenite, seem to be surrounded more by thin bands of phosphide than is the case if pearlitic granulation takes place.

Getting back to iron sulphide and manganese sulphide, the theory has been held, or was held for many years, that there were mysterious networks throughout the material which caused a weakening of the iron and those networks were iron sulphides. We examined irons where the manganese was relatively high compared to the percentage of sulphur. If there was a considerable amount of iron sulphides, and this had been thrown out as a female constituent around the grain, you could expect (depending on the rate of loading, of course) inter-crystalline fracture rather than trans-crystalline. So far as our limited observations have gone there seems to be no vast difference, trans-crystalline breaks occurring quite readily. The inter-crystalline breaks are most often along graphite planes.

In the paper Mr. Shaw states—(I don't believe he is quoting here, I haven't given it careful enough attention to say whether it is Mr. Shaw's statement or someone else's statement), "The results show that manganese sulphide, even in the presence of an excess of manganese, will be partly converted into iron sulphide and enter the metal, therefore the

reaction is reversible." That, Mr. Shaw, is a molecular relationship. The lag of mass action denies the reaction from taking place 100 per cent because of the mass of iron compared to the mass of manganese. But the bulk of the sulphur seems to go to the manganese.

J. SHAW: I am quite in agreement with Mr. Bolton, who, I take it, means that any iron sulphide present is in solution with the iron, at all events to the amount found in ordinary foundry irons and to that limited amount cannot be separately identified. Hence it cannot form a source of weakness round the crystal boundaries. If it existed as a separate identity it is difficult to see how it could effect the state of the carbon with regard to the reversible form. These are quotations from Rholl's paper and the recent findings of Messrs. Herty and True.

J. W. BOLTON: That is true. The point I was making, you have motion in both directions in any kinetic equilibrium. There is a very vast amount of iron, Fe, in comparison with a very small amount of manganese, with a consequent displacement of equilibrium between the relationships of manganese and iron.

O. W. POTTER: We have done some investigating along this line quite recently. We don't claim to know very much about sulphur, but I will tell you just a little about what we have done. We tried to examine this from a microscopic standpoint. We found inclusions and set about trying to determine what the inclusions were. We found it was rather difficult and we didn't satisfy ourselves entirely as to what they were. We concluded they were various things; oxides, sulphides, and possibly silicides.

We went a little further to investigate the condition of the carbon. We took the carbon flakes and magnified them to a great magnification, 1000 and even 2000 diameters, and we found the network that has been spoken of. And then we ran across some investigations that were being put forward in regard to some gas inclusions which led us to believe that these may have some relation to the sulphur content. We made sulphur prints of these specimens. We found in some cases we seemed to correlate sulphide with the graphite flakes, and from this we have drawn the tentative conclusion that possibly these sulphides are associated with the graphite flakes in some form and may be associated with the dissolved gases.

J. W. BOLTON: It so happened that five, or nearly six, years ago, we had occasion to do this same work. On observing sulphur prints we at once noticed that these sulphur prints, instead of seeming to show distribution of sulphur, certainly indicated a distribution of carbon, graphitic carbon, in the iron. After quite a bit of study (we had to develop our own microscopic methods of attack) we tried the following scheme out and it showed the why and wherefore of this phenomenon which

Mr. Potter has called to our attention. We took a polished piece, very carefully polished, showing graphite and sulphide in the unattacked matrix. We treated the sample with dilute phosphoric acid, about 2 per cent, and put that under the microscope, the vertical microscope, because we found that to be the better. We were able to find inclusions of sulphide irrespective of the graphite flakes and a number of sulphide inclusions within the flakes. Under the action of the acid H_2S was evolved from the sulphide particles within the flakes of graphite. The flake structure was permeable to the action of phosphoric acid and therefore it was much easier for the sulphide particles within the graphite flakes to be attacked and evolve hydrogen sulphide.

Allowing a longer time, we found that after most of the sulphur had been evolved from the sulphides in the graphite, the other sulphides then began to decompose. In other words, this is simply a question of the ease with which the acid can attack these sulphur forms.

Going further and making a little higher magnification investigation of this matter, we found very many instances where you would have a graphite flake surrounded by ferritic flakes, between the flake of graphite and pearlite. In certain cases we would find conditions had so resulted that there happened to be one of these sulphur forms between the graphite flake and the pearlitic area. There always seemed to be a very definite tendency for the pearlitic cementite to associate with the globules of sulphide. As a matter of fact, the ferrite extended all around the sulphide island, giving it the appearance of a many-legged bug, with streamers of cementite laminæ.

The graphite being so great in volume compared to the volume of sulphur forms it has a very much more profound effect in larger castings than these latter. We have noted in a practical way this phenomenon: That in higher sulphur irons there was a tendency for finer grain.

I am going to jump ahead here and show the action of sulphur forms compared to the action of temperature. When you carry your temperature high enough, you get proper nuclei. I want to say I believe, and have reason to believe through practical experience, in larger castings sulphur forms have some effect on nuclei formation.

Take crystallization—I think a number of you gentlemen have probably crystallized various salts. Now, if you want to get idiomorphic crystals you have to get your crystals completely dissolved first. Then sub-cooling is easy. Second, if you want to make a fine crystal, you take a stirring rod and vibrate it and that vibration breaks up the crystals and forms many nuclei. And the third point, in certain cases sulphide forms as nuclei for graphite just as dust particles do in salt solutions. These general laws hold good in the recommendations of Piwowarsky, Irresberger and myself.

E. Longden: I am going to digress from these papers a little. I must say that Mr. Shaw's paper is certainly excellent. There is no man

in England who we admire more and who we look up to more than Mr. Shaw, and whom we try to understand. However, I would like to give my personal opinion of Mr. Shaw. Mr. Shaw is too wise to give any definite conclusions, I think, on cast iron. It is too hard to understand. It has been stated there has not been much research made. There has been a tremendous amount of research carried out in cast iron. Mr. Shaw himself has done a great deal, but he is reluctant to give any definite conclusions.

For instance, in test bars; I am thinking of some tests I carried out on gas engines. We cast two test bars vertically on the bottom of the crank case. The bars were not placed in the same position. And on one bar you get 11½ tons, on another you get 8 tons, and on another you get 12 tons, and on another you get 7¾ tons, with the same mold and the same temperature. Now I am of the opinion that we don't get complete analysis today, and we won't until we do take into account the effect of gas, dissolved effect of mold gas on gray iron. Until then we shall not arrive at definite conclusions.

E. J. LOWRY: This paper is really a very wonderful paper and Mr. Shaw certainly must know a great deal about sulphur, to correlate all the citations that he has made. Technically it is really wonderful. But there are a few things I would like to ask questions on. On page 814 you have listed there a formula by Rohl. You say down below, "therefore the reaction is reversible." I think that should be qualified. The only citation I have been able to find is by a man from England in which that reaction becomes reversible in the presence of oxide.

It is, you say, the loss of sulphur. It has been my experience you lose sulphur in different ways. For instance, in an experiment run in a blast furnace two years ago we got a great sulphur reduction, which we attributed to the alkaline reagent used. We checked this test and found the actual reduction was but in a small part due to the alkaline action, the manganese was the actual reagent during the desulphurization. In the cupola it is common practice in this country to put in ferro-manganese to desulphurize, or prevent the pick-up of sulphur rather than the desulphurization. I think Mr. Rother has had a great deal of experience with the use of ferro-manganese in the cupola. The point that interested me most was on your chill work, in which you cite, I think, a loss between your chill test plug and your chill casting of 4.3 per cent. That is in the first chill test plug. That practice isn't in accordance with ours here. We expect to lose 20 to 25 per cent. It may be the size of the bar and the way you cast it.

The blast furnace temperatures usually run between 2450 and 2650 degrees Fahr. Our furnace practice is to run hot and not leave the irons in the furnace any longer than possible. For instance, Bolton here up at Moline will get an average cupola temperature of 2750, he will run consistently between 2750 and 2650, and there you get a hotter iron from the cupola than the blast furnace.

I ran experiments eight years ago using bull ladles, tapping half the ladle and letting the other half freeze, and there was no appreciable difference.

With regard to your statement about the measure of chill blocks in this country, it all depends on the foundry you go into. You go into Wheeling and they measure right down into the middle of the spray, but at Ansonia they measure down to the first spot that occurs. And you go to another plant and they are just measuring half the distance between the first spot and where the spray begins.

J. SHAW: The reply to Mr. Bolton covers the question of the reversible action of sulphur and manganese. With regard to the measurement of the chill test mentioned by Mr. Lowry, our method is clearly stated at the beginning of the paper, we measure to the first spot of grain. I have come across other methods in this country such as you have stated. The question of loss between test and roll depends entirely on the ratio of manganese to sulphur on the same size roll. I believe it is possible by a manganese addition to the cupola to lessen the amount of sulphur picked up from the coke, but it is so difficult to say what takes place in the cupola. My statement with regard to loss of sulphur is this: That I have never found any reduction of sulphur take place in a ladle of metal even with manganese additions. That when MnS is present, this lighter material does not settle at the top, but is swirled up and down by convection currents exactly as will tea leaves or sawdust in a beaker filled with boiling water. This movement does not stop probably until the dendrites are formed on the casting face. Thence most of the MnS is trapped, while a little may escape to the top of the casting and give the higher sulphur usually found at this point. A peculiar thing about this is the fact that you hardly ever find an increase of Mn pro ratio to the MnS sulphur at the top of the casting.

J. W. BOLTON: One question that comes up here, many people are trying to reduce shrinkage by the use of higher manganese. I don't know that they are accomplishing their aim.

E. J. LOWRY: I can answer that. It is because the cry of all the foundrymen is, "Ship us high manganese pig iron." And the furnace would rather use lower grade ore and produce lower amounts of manganese. When that paper you refer to was published it was common practice to send Southern iron up North. But now the Southern irons remain in the South, and the Northern irons remain in the North, and the manganese has crept up appreciably.

J. W. BOLTON: It is a very lamentable fact that if you take a list of all the so-called high test irons, 40,000 pounds and over, we would have to throw most of them out on our chemical specifications because most of it contains over .10 sulphur.

J. Shaw: I can't say why, but it is a fact that the iron which is giving fairly good results on our side will run up to .15 sulphur.

It would be helpful if I could obtain an opinion of the value of the evolution method for sulphur. I have not so far seen one that came within 0.03 per cent on a 0.15 per cent S. It is often important to have a return more quickly than by the gravimetric method.

J. T. MacKenzie: The first thing I want to say, for instance, on page 843 of Mr. Shaw's paper where he mentions experiments, he shows the addition of 0.5 per cent of manganese increased the graphitic carbon from 1.93 to 2.40. Mr. Shaw assumes oxidation was taken care of there. I can hardly agree with him that was so, because in looking over some of Coe's work on phosphorus there is very considerable evidence of oxidation, and carbon is dropped off from 3.0 per cent to about 2.20 per cent while he was conducting the heat. So that I still believe that a good deal was due to deoxidation instead of the addition of manganese.

On the subject of the determination of sulphur, we got a sample of French pipe some time ago which was perfectly gray. And the evolution itself was only 0.06 per cent, whereas the gravimetric method gives 0.10 per cent, a difference of four points. We have found and the Bureau of Standards has found, that titanium is very pronounced in its effect, in fact, with 0.25 per cent titanium annealing does not improve the recovery of sulphur very much. When you have enough zirconium you get no sulphur by evolution. Now nearly all steel metallurgists say that the sulphur that is locked up that way doesn't effect the metal, so I don't know. But a good deal of the errors in high sulphur work come from using a value obtained by evolution on a standard run gravimetricly. We have done some work with the Bureau of Standards on annealing and we find where you have not titanium and zirconium present you can secure practically all the sulphur after half an hour annealing. But the tendency in this country is to use the theoretical value of your solution and not use any factor based on a standard whatsoever.

J. Shaw: The experiment relating to the increase of graphitic carbon due to an addition of 0.5 per cent Mn was carried out by Professor Turner of Hague, not Coe. The results are to be found in the I. of S. I. Journal for 1910, No. 2. Would it not be as well if Mr. MacKenzie tried this experiment out for himself? Let him make additions of say 0.06 per cent Mn to a small ladle of metal and note the reduction of chill even when the Mn is three times the S. I wish to thank him for his remarks on the evolution method for sulphur.

A Shearing Test for Gray Cast Iron

By G. K. Elliott,* Cincinnati, O.

Gray cast iron rarely is tested by shearing in this country, but a certain type of shearing test for some time has been advocated and practiced as suitable for gray iron castings in France and possibly in other European countries, the Fremont shear testing machine being the apparatus used. The committee on gray iron castings of the American Foundrymen's Association, having had the subject of tests under consideration for some time, several years ago asked the association to secure for the committee's research one of these machines. The object was to obtain more light on testing gray iron, a subject which in recent years has become the cause of much vigorous international argument among foundrymen and metallurgists. Upon receipt the machine was sent in turn to three members of the committee for trial and comment, the present paper containing results and experiences gained by the third of these members. A supplementary paragraph contains results secured by one of the other members.

The Fremont Machine

The Fremont machine is a beam-acting, single-shear apparatus which shears short lengths from small cylinders (5.64 mm. or 0.222 inches in diameter and about one inch long) previously drilled or trepanned from castings by means of a core-drill or hollow milling cutter. Also the machine will accommodate test pieces with a square section of 5 mm. x 5 mm., although none of these is used in the present tests. The round holes left by the drill are about 0.4 inch (10.5 mm.) in diameter, and it is claimed that these can be plugged and the castings used as originally intended after the tests have been made; or else the sample can be taken at some place where a hole would be made during the machining of the casting.

A photograph of the machine is shown in Fig. 1. By the hand-operated worm (A) the poise (B) which in the present machine

*Deceased.

happened to weigh exactly 94 pounds with all its attachments, is run out on the beam (C) until the blades at (D) shear the test piece (F). Since the length removed is short several tests can be made from each piece.

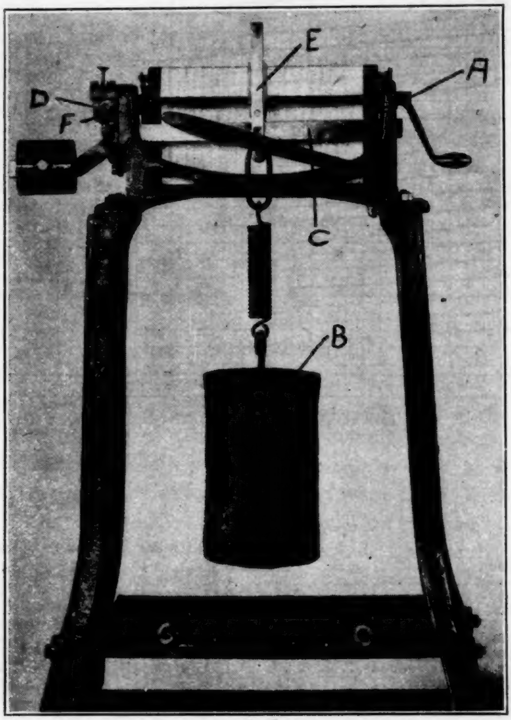


FIG. 1—FREMONT SHEARING TEST MACHINE

The Recording Apparatus

Attached to the poise-carrier at (E) is a pencil which traces a slightly downward dipping horizontal line as the poise travels out the beam. A number of these autographic lines are shown in Fig. 2. The horizontal length of the lines represents the load,

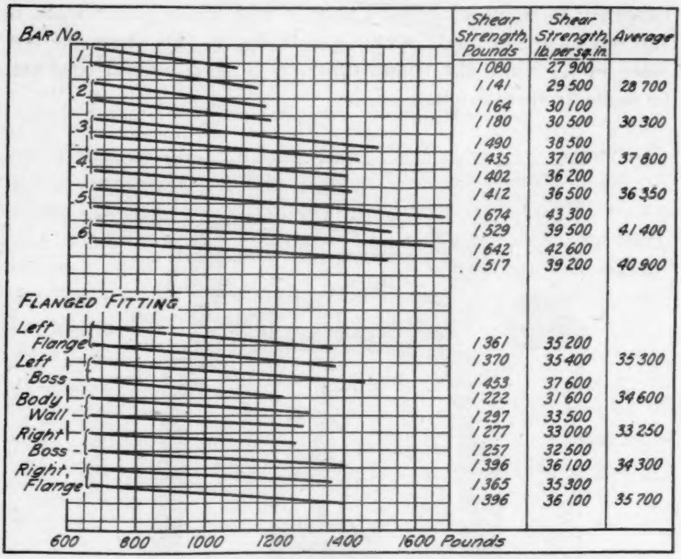


FIG. 2—AUTOMATICALLY RECORDED SHEAR LINE CHART

Table No. 1

BARS

	Bar 1	Bar 2	Bar 3	Bar 4	Bar 5	Bar 6
Total Carbon	3.50	3.51	3.40	3.46	3.16	3.22
Silicon	2.00	1.96	1.60	1.69	1.50	1.54
Manganese	0.57	0.55	0.61	0.66	0.56	0.61
Phosphorus	0.51	0.56	0.42	0.45	0.35	0.36
Sulphur	0.081	0.073	0.077	0.072	0.063	0.070
Shear, pounds per square inch	28,700	30,300	37,800	36,350	41,400	40,900
Tensile, pounds per square inch	21,900	23,700	28,500	27,700	36,700	35,900
Transverse strength, pounds	2,700	2,875	3,575	3,510	4,100	4,040
Deflection in 12 inches	0.14	0.13	0.157	0.162	0.154	0.150
Drop Test, pounds	420	600	1,020	1,020	1,260	1,260
Scleroscope hardness	38	40	40	40	42	42
Brinell hardness	179	196	196	196	217	217
Rockwell hardness	B-90	B-93	B-94	B-93	B-98	B-97

FLANGED PIPE FITTING

	Left Flange	Left Boss	Body Wall	Right Boss	Right Flange
Total Carbon	.....	.....	3.45	.....	.....
Silicon	.....	.....	1.72	.....	.....
Manganese	.....	.....	0.66	.....	.....
Phosphorus	.....	.....	0.42	.....	.....
Sulphur	.....	.....	0.065	.....	.....
Shear, pounds per square inch	35,300	34,600	33,250	34,300	35,700

while the dip is partly a reflection of the amount of shearing deformation, the degree depending upon the rigidity and relative position of the blades.

Since no chart sheets accompanied the machine and since the beam bore no calibration markings, we were forced to make use of such cross-section paper as was at hand and to calibrate the machine after carefully determining its constants, which was not an easy task. It was found that the position of the poise on the beam at the beginning of each test is 2.93 inches from the axis, representing an initial stress of 670 pounds on the specimen, equivalent to about 17,500 pounds to the square inch.

Drilling Test Cores

When it came to drilling test cores with the hollow drill which came with the machine, trouble was met. As received this drill had no means of ridding itself of the chips which collected in the hollow, where they exercised on the core being cut, an irregular grinding action which produced pieces elliptical in cross section instead of perfectly round as they should be for accurate results. This was remedied by making openings in the wall of the drill to allow the chips to escape as fast as formed. Reasonably accurate test pieces even then were rather difficult to obtain. The corrected drill is shown in Fig. 1 on the stand directly under the poise of the machine. To its left is another drill lying on its side; on its right are two test pieces ready for test, while at the extreme right and left are pieces of arbitration bars with the test cores drilled but not removed.

Making The Tests

In making the test the specimen is held in two round holes of practically the same diameter as the piece, one hole being in each shear blade. It was found advisable to have the fit here fairly close, because specimens much under size so as to lie loosely in the holes tended to throw the moveable shear blade, which in this particular machine was rather free to move horizontally, away from the plane of true shear, introducing thereby a small but potent amount of bending moment. In fact the best results were

obtained when the test pieces were exactly 5.64 mm. or 0.222 inches in diameter—a size which fitted snugly in the holes of the shear blades. Since it was practically impossible to make the hollow drill deliver pieces with this degree of accuracy, in all the tests reported in the present paper the writer resorted to the practice of first cutting the specimens with a slightly over-size drill and finishing them to exact size on a small precision lathe. This was very arduous and time consuming but for even fair accuracy seemed necessary. Our main criticism of the test in fact is the great trouble necessary to obtain reliable test pieces which are perfectly round in section and of the specified diameter. Something more than a mere hollow drill for preparing the sample seems necessary as well as some apparatus for shearing which is more rigidly and carefully constructed than the one at our disposal.

How the Tests Were Conducted

The Fremont shearing tests recorded here were made with the object of discovering their relation to the results of other kinds of mechanical tests on identical iron castings. For this good subjects seemed to be arbitration test bars as described in A. S. T. M. Standard Specifications "A 48-18." First the bars were given the customary transverse test between 12-inch centers. One of the resulting pieces was sufficient for both the tensile and the shearing tests, the sample for the shearing test being drilled longitudinally from the center of the fracture of the transverse test. The other piece from the transverse test was used for the scleroscope, brinell and rockwell hardness tests and for the drop test. All the hardness tests were made about 1/8 inch beneath the original surface of the bars and therefore represent somewhat stronger iron than the shearing tests made in the center of the cast bars. For the drop test the piece was laid upon supports six inches apart and a 20-pound tup dropped on its middle from successive heights of six, seven, eight, nine, ten, etc., inches until fracture occurred, the total number of inch-pounds being recorded. At the end there were at hand from the same original bars, data from transverse tests, tensile tests, hardness tests of three kinds, and drop tests, to be compared with shearing test data.

In addition a 6-inch flanged pipe fitting made from the same ladle of iron as one of the bars, was sampled in several places and shearing tests made, which gave a comparison between the shearing strength of an iron in a commercial casting and in an arbitration test bar; also there was afforded a comparison of the shearing values of the iron in several parts of a single casting.

Discussion of Data

Fig. 2 shows the characteristic graphs automatically recorded by the Fremont apparatus for each of the pieces tested and the values obtained. Each shearing was made twice on the same piece and the results averaged.

Table 1 records the chemical analyses of the pieces and results of the several mechanical tests.

The chemical analyses reveal three grades of iron in the arbitration bars. Bars 1 and 2 have the highest total carbon and silicon; bars 3 and 4 the same carbon as bars 1 and 2 but lower silicon; and bars 5 and 6 have both carbon and silicon lower. Naturally the irons are progressively stronger in the order given. The values for the Fremont shearing test parallel those for the transverse, tensile, hardness and drop tests in an orderly manner indicating it to be a reliable index of the general strength of the iron. Of course under less favorable conditions in which the shearing sample might be taken from a weak spot of a more intricate casting than those used in the present tests, the preceding statement manifestly would not be true, nor could such sample be considered representative of the general quality of the iron in the casting itself.

The shearing values of cores drilled from various locations on the 6-inch flanged pipe fitting are especially noteworthy because the casting was made from the same iron as bar 4. A study of the results enables us to judge the relative strength of a given iron when cast in standard arbitration test bars and in a cored, cylindrical casting weighing about one hundred pounds with metal thickness varying from about ¾ inch in the main body wall to twice that in the end flanges. We find that the average shearing strength of the small test pieces drilled from the heart of the

arbitration bar is 36,350 pounds per square inch, while in the flanged casting it is only slightly lower, being 35,300 and 35,700 pounds in the two flanges, 34,600 and 34,300 pounds in two bosses located about one third the distance from each flange, and 33,250 pounds in the body wall midway between the flanges. The maximum difference is between the bar and the body wall and is only 3,100 pounds, equivalent to 8½ per cent. However in no case is the strength of a sample from the cast fitting equal to that of the test bar. Also it is interesting to note that there is little difference between the various parts of the casting which were sampled for the test.

It will be noted that the specimens drilled from the heavy bosses of the flanged castings show a rather wide difference in shearing strength. This is accounted for by the fact that the specimens were so sheared as to represent the iron at two different depths from the casting's surface. This condition did not exist in the samples from the other less thick parts of the casting which explains the closer agreement in the tests of those parts. Two additional tests on one piece drilled from a boss which were made so as to represent the iron very near the surface of the casting and at the center of the thickest part, gave 38,300 pounds per square inch shearing strength at the outside and 31,600 pounds at the center. Of course this is explained on the grounds that the iron near the outer surface having cooled more rapidly than that in the interior, will have more combined carbon and therefore will be stronger. For true comparisons therefore in cases like the one just cited, tests should be made either at a specified distance from the outer end or else at several fixed intervals along the specimen and the results averaged. In the shearing tests made on specimens from arbitration bars the strength does not vary because the pieces all were taken longitudinally from the center of the bars where the cooling rate was the same throughout their length.

A Modified Test Apparatus

Since the Fremont shear apparatus is not very available in this country it occurred to us that the same test could be made with

apparatus which is simpler, cheaper and more within reach of the average foundry. Accordingly there was made a device for either single or double shear which is shown in Fig. 3. Mounted on the platform of a standard universal testing machine it is illustrated in Fig. 4. It consists of two ½-inch steel plates spaced ½ inch apart with a close fitting plunger shear blade free to move between. In the shear blades are several holes of various diameters to accommodate slight variations in the size of test pieces, relieving the necessity of adhering so rigidly to an exact diameter

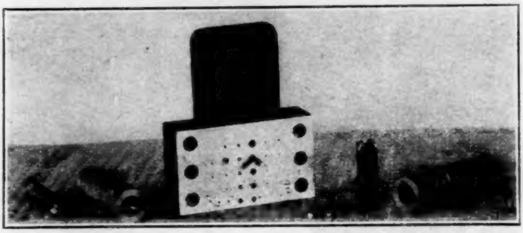


FIG. 3—SINGLE OR DOUBLE SHEAR TESTING DEVICE

and so hastening production of the pieces. The apparatus also was built so that the shear blades cannot deviate from the plane of true shear and so introduce slight bending moments into the tests, which was a point at which the Fremont machine was slightly at fault.

The overall dimensions of this shearing device are 5 x 3 x 1½ inches. It has to be supplemented with some form of testing machine which can apply and weigh loads which seldom, if ever, will run as high as 2,000 pounds* (equivalent to about 52,000 pounds per square inch for a 0.222 inch diameter bar). Either single or double shearing tests can be made with the apparatus although the usual length of specimen allows only one double shearing. The Fremont machine is fitted only for single shearing.

It was noticed that where duplicate tests were made with the two machines the Fremont consistently gave slightly lower results than the other, which probably was due to the new apparatus offering conditions more favorable to pure shearing.

*This is for single-shear tests; for double-shear the loads will be twice as great.

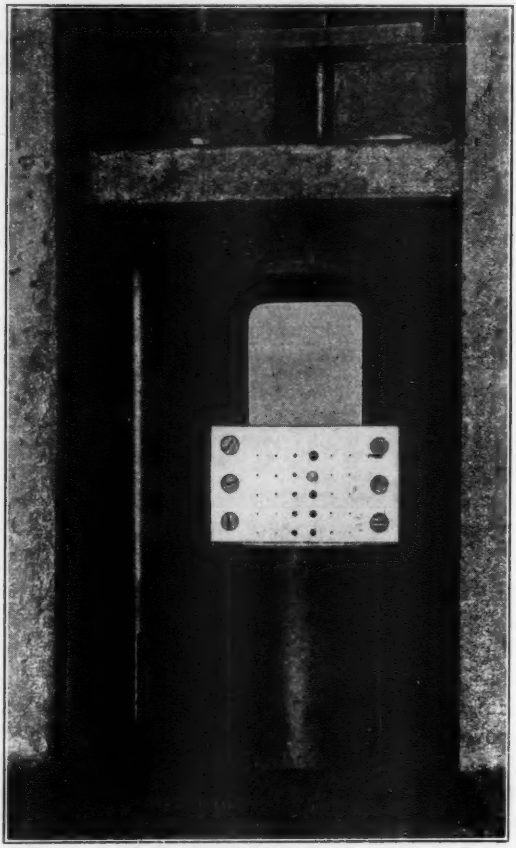
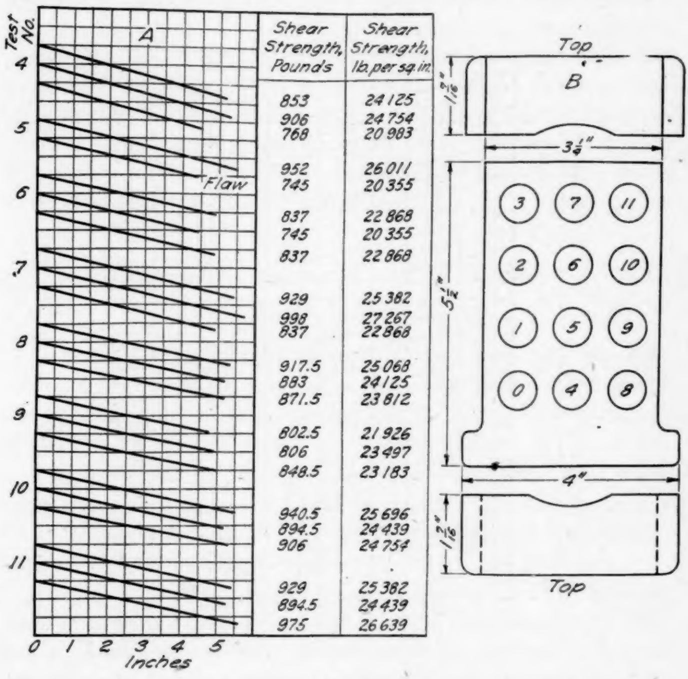


FIG. 4—SHEAR TESTING DEVICE USED IN CONNECTION WITH A UNIVERSAL TESTING MACHINE

Conclusion

On account of the deficiencies found in the machine used in his investigation, the writer's judgment is not entirely favorable to the Fremont shearing test as a routine test to replace the transverse so commonly used in this country, but on the other hand

he is quite kindly disposed to it as a means to a much needed line of research. The care and time necessary to secure reliable samples seem to militate against it for routine testing, and there is a question in the minds of some persons whether results obtained from so small portions of a relatively large casting are as indicative of the quality of either the iron or the casting as are separately cast test bars made from the same metal as the casting. Unless the small shear specimens are intelligently selected from



Shear Strength, Pounds	Shear Strength, lb. per sq. in.
853	24 125
906	24 754
768	20 983
952	26 011
745	20 355
837	22 868
745	20 355
837	22 868
929	25 382
998	27 267
837	22 868
917.5	25 068
883	24 125
871.5	23 812
802.5	21 926
806	23 497
848.5	23 183
940.5	25 696
894.5	24 439
906	24 754
929	25 382
894.5	24 439
975	26 639

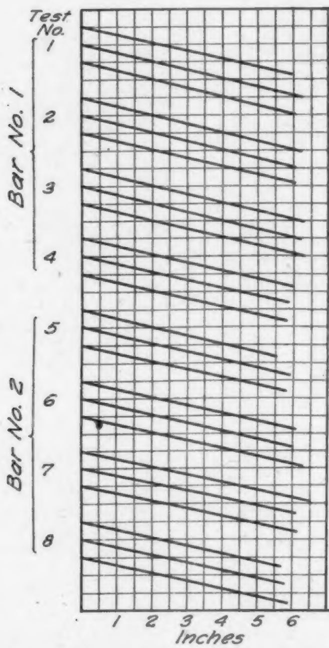
FIG. 5—A DETERMINATION OF THE SHEARING STRENGTH OF CAST IRON WITH THE FREMONT MACHINE

A. Chart showing the distance the shearing weight had traveled at the time of shear. (Data by W. H. Rother.)

B. Drawing of casting tested showing the location of the test specimens. Chemical analysis: Total carbon, 3.20; combined carbon, 0.60; graphitic carbon, 2.60; silicon, 2.00; manganese, 0.62; phosphorus, 0.78; sulphur, 0.09.

the casting they may be misleading; in fact, in matters of specification and contract it would seem that the location to be drilled for samples would have to be definitely stated.

However, there is an important field in which the shearing test of small specimens taken from castings, should be of great practical value. This is in making thorough explorations of castings for the purpose of locating their points of weakness. Data thus obtained should be of more than passing interest to designing engineers who are not always happy in their layout of foundry



Shear Strength, Pounds	Shear Strength, lb. per sq. in.
1032.5	28 210
1078.5	29 467
1055.5	28 838
1090	29 782
1055.5	28 838
1055.5	28 838
1101.5	30 095
1090	29 782
1101.5	30 095
1044	28 524
1009.5	27 582
1009.5	27 582
963.5	26 325
1032.5	28 210
998	27 267
1055.5	28 838
1055.5	28 838
1101.5	30 095
1147.5	31 352
1067	29 135
1067	29 135
986.5	26 953
998	27 267
1021	27 892

FIG. 6—A DETERMINATION OF THE SHEARING STRENGTH OF SPECIMENS CUT FROM ARBITRATION TEST BARS USING THE FREMONT MACHINE

(Data by W. H. Rother.) Chart showing the distance the shearing weight had traveled at the time of shear—transverse test, bar 1, load in pounds, 3,020; deflection, 0.13 of an inch; bar 2, load in pounds, 3,150; deflection, 0.11 of an inch. Chemical analysis: Total carbon, 3.30; combined carbon, 0.60; graphitic carbon, 2.70; silicon, 1.75; sulphur, 0.085; phosphorus, 0.385; manganese, 0.65.

patterns. Foundrymen also would benefit because points of structural weakness frequently are centers of molding troubles. We can see a splendid future for this type of research and as a means to its accomplishment the shearing test described may well invite the careful attention of engineers, foundrymen and metallurgists.

In the following concluding section of the paper we take pleasure in showing some results obtained with the Fremont machine by W. H. Rother,* who also is a member of the committee. Fig. 5 shows the results he secured from specimens drilled from a solid casting which, according to the original chart, was approximately 5¼ by 3¼ by 1⅜ inches in dimension. The results fail to indicate any great difference in shearing strength in the various parts of the casting, although Nos. 7 and 11, which probably received the most rapid cooling, are slightly stronger than the others. Fig. 6 shows the results which Mr. Rother obtained with specimens taken from arbitration test bars.

Written Discussion—By W. H. Rother,* Buffalo, N. Y.

Discussing the shearing strength of cast iron with the Fremont-Portevin machine there is a very important point I would like to bring up. That is the size of test piece for which this machine is made.

In the Fremont test the sample is so small that any slight error is multiplied to a considerable extent in the final computation. When testing with a large diameter sample the final computation would not be affected appreciably by a slight error.

Table 1, of Mr. Elliott's paper, shows that in all the tests made on shearing and tension bars that the shearing strength per unit area was much greater than the tensile strength per unit area. According to the best authorities the shearing strength of gray cast iron is equal to the tensile strength. It is to be noted that in making the shearing tests all of the small specimens were drilled from the center of the bars. This then gave metal from the weakest part of the bar which it would seem would naturally have

*Buffalo Foundry and Machine Co.

a shearing strength somewhat lower than the tensile strength determined on a larger section.

Recently we made some shearing tests on bars that previously had been tested in tension. A single shearing block was made to take a test piece 0.875 inch in diameter.

The shearing was done on a 100,000 pound tensile testing machine.

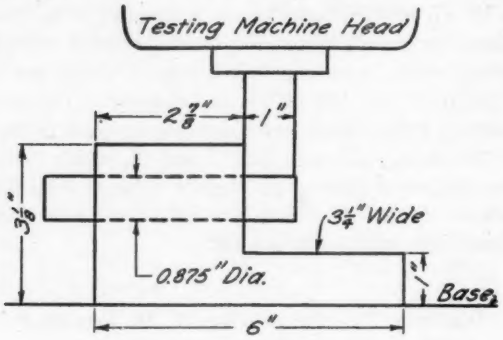


FIG. 1—SHEARING TEST SET-UP

The following figures give some results obtained on the shearing and tension tests:

Tension	Shearing
23,780	19,745
25,940	22,450
23,200	19,040
36,250	26,270
31,000	22,950
32,830	22,280
30,930	22,230

You will note from these tests that the shearing strength is considerably lower than the tensile strength. This is just the opposite of the results obtained by Mr. Elliott on the Fremont-Portevin machine.

This shows the difference in the shearing results obtained with a small diameter test specimen and one of larger diameter. The question then is one dealing with the size of test specimen: Are the results obtained from such small test pieces as reliable as those obtained from one of much larger cross-section? We do not believe that they are.

The Effects of Various Alloys on the Growth of Gray Iron Under Repeated Heatings

By R. R. Kennedy* and G. J. Oswald,* Dayton, O.

The work described in this paper was undertaken with the idea of developing a gray iron having a slow rate of growth under repeated heatings above the critical range, and which could be produced by the addition of various alloys to gray iron in the ladle.

Outerbridge[1] made a scientific study of this subject of growth of cast iron. Carpenter and Rugan[2], and later Carpenter[3] alone, made very thorough investigations from which they concluded, that growth is due to oxidation of the graphite by the oxygen of the air, hence, that all cast irons containing graphite grow on heating above the critical range, the growth being accelerated by silicon, but retarded by sulphur, phosphorus and manganese. They developed an iron containing .4 per cent silicon, 2.7 per cent carbon and 1.6 per cent manganese which showed practically no growth under repeated heatings. Due to its very low silicon content, this iron could not be made in a gray iron foundry. Okochi[4] and Sato observed that a small amount of growth takes place when cast iron is heated in a vacuum. They also found that the same amount of growth takes place in cast iron when heated in an atmosphere of hydrogen, as when heated in air. Andrew and Hyman[5], also working on the problem of growth in cast iron, found that nickel and aluminum accelerate growth while chromium retards it.

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*Research Department, National Cash Register Co.
[1] Transactions, A. I. M. E., 1905.
[2] Journal of The Iron and Steel Institute, 1909, No. II.
[3] Carpenter, ibid., 1911, No. I.
[4] Journal College of Eng., Tokio Imperial Univ., 1920.
[5] Andrews, J. H., and Hyman, H., Journal Iron and Steel Institute, 1924.

Iron Used

The iron used in this recent investigation was cupola melted metal, only the regular foundry mixtures being used. Bars numbered 3 were poured with the addition of 1 per cent of metallic manganese to a hand ladle of the lower silicon mixture. To the high silicon iron used in bars numbered 4, 1 per cent phosphorus in the form of ferro-phosphorus was added. In making bars numbered 5, 1 per cent of nickel shot and .5 per cent of chromium in the form of ferro-chromium were added to a ladle of the lower silicon iron. The iron did not take up all of the chromium due to its high melting point.

As the bars were poured from different heats, some variation in composition occurs.

The analysis of the various bars is given in Table 1.

Table 1

COMPOSITION OF BARS USED

Bar No.	S Per Cent	P Per Cent	Mn Per Cent	Si Per Cent	Total Carbon Per Cent	Ni Per Cent	Cr Per Cent
1	.070	.60	.58	2.90	3.12	....	...
2	.080	.52	.51	2.19	3.54	....	...
3	.068	.61	1.51	2.39	3.41	....	...
4	.076	1.56	.52	2.88	2.96	....	...
5	.083	.49	.45	1.84	3.23	1.12	.17

Method of Conducting Experiments

The iron was poured into bars 1¼-inch in diameter by 14 inches in length. These bars were cut in two and machined down to a diameter of 1 inch and a length of 5 inches. The ends of the bars were carefully ground parallel. Two bars from each mixture were used in this work.

The length of the bars was measured by means of a surface block, a surface gauge and a set of Johansson blocks. The diameter was determined by means of a micrometer, care being taken to make the measurement in the same place each time. The first measurements were made to the nearest ten-thousandth of an inch, but after a few heatings, the warpage of the bars was so great that such accuracy was impossible and they were therefore measured to the nearest thousandth.

To prevent excessive scaling, the bars were packed in a steel pot with cast iron borings and the lid was luted with fire

clay. The pot was heated in a gas-fired muffle furnace to a temperature of 1550 degrees Fahr. plus or minus 50 degrees, the duration of each heat being 3 hours. The bars were unpacked and measured after the 1st, 6th, 11th, 25th and 50th heatings. Results are as shown in Table 2.

Rate of Growth

Bar 1-A, poured from the high silicon mixture had the highest rate of growth of any bar tested. It was badly cracked on the surface. Bar 1 did not grow as rapidly as Bar 1-A, but it also contained a number of surface cracks.

Bars 2 and 2-A, poured from the lower silicon mixture, had

Table 2

GROWTH OF BARS UNDER REPEATED HEATINGS TO 1550° F.

	Growth in Length of 5 Inches					Growth in Diameter of 1 Inch					
Bar No.	1st Heating	6th Heating	11th Heating	25th Heating	50th Heating	1st Heating	6th Heating	11th Heating	25th Heating	50th Heating	Increase in Volume Per Cent
1	.0168	.0375	.0917	.230	.422	.0036	.0076	.0217	.038	.078	26.24
1-A	.0194	.0424	.1134	.201	.548	.0048	.0096	.0309	.040	.117	38.48
2	.0323	.1178	.3438	.457	.511	.0070	.0248	.0733	.096	.095	32.20
2-A	.0358	.1258	.2428	.387	.495	.0075	.0248	.0507	.084	.100	32.77
3	.0249	.0477	.1467	.324	.542	.0056	.0099	.0207	.064	.113	37.25
3-A	.0230	.0530	.1350	.288	.487	.0055	.0098	.0255	.053	.092	30.75
4	.0055	.0102	.0632	.112	.169	.0012	.0032	.0179	.044	.067	17.63
4-A	.0056	.0132	.0472	.086	.137	.0022	.0032	.0136	.032	.061	15.64
5	.0293	.0889	.2589	.387	.444	.0060	.0192	.0514	.079	.084	28.15
5-A	.0291	.0993	.2613	.393	.436	.0062	.0192	.0561	.079	.086	28.32

*Growth given in inches.

a high rate of growth, but neither bar showed any evidence of surface cracks.

Bars 3 and 3-A, from the high manganese mixture, also had a high rate of growth, showing that this quantity of manganese did not have a retarding effect on growth of iron of the composition used. Both of these bars contained slight surface cracks.

Bars 4 and 4-A, from the high phosphorus mixture, showed the minimum growth of any bars tested. They were in good condition at the conclusion of the tests and showed no evidence of surface cracks.

The tests showed that the addition of nickel-chromium to the low silicon mixture had a small retarding effect on the rate of growth. These bars likewise gave no evidence of cracking.

Macrostructure of Iron

All bars on examination were found to contain a core of fairly sound metal surrounded by an outer area which was spongy in appearance. The size of these cores varied, the high silicon bar, 1-A, which showed maximum growth, having the smallest core, and the high phosphorus iron, bars 4 and 4-A, having the largest cores of sound metal.

Experiments With Deoxidized Iron

As no attempt had been made to deoxidize the iron used in these bars, it was thought that any gases present might have had an accelerating effect on the rate of growth. As in the above

Table 3

COMPOSITION OF BARS USED IN DEOXIDATION EXPERIMENTS

Bar No.	S Per Cent	P Per Cent	Mn Per Cent	Si Per Cent	Total Carbon Per Cent
6	.076	.58	.63	2.93	3.21
7	.080	1.67	.64	2.80	3.06
8	.074	.60	.60	2.81	3.24
9	.069	.57	.69	2.98	3.33

NOTE: Bars numbered 6 and 7 poured from iron deoxidized with titanium. Bars numbered 8 and 9 are control bars. Iron was not deoxidized.

Table 4

GROWTH OF BARS POURED FROM DEOXIDIZED IRON

Bar No.	Growth in Length of 5 Inches: 1st Heating Inches	6th Heating Inches	11th Heating Inches	25th Heating Inches	Growth in Diameter of 1 Inch: 1st Heating Inches	6th Heating Inches	11th Heating Inches	25th Heating Inches	Per Cent Increase in Volume
6	.022	.031	.043	.076	.0046	.0094	.0121	.0228	6.34
6-A	.029	.039	.049	.079	.0055	.0088	.0128	.0259	6.90
7	.019	.026	.034	.057	.0037	.0060	.0108	.0224	5.86
7-A	.020	.028	.037	.056	.0048	.0078	.0129	.0202	5.18
8	.036	.047	.075	.193	.0077	.0113	.0194	.0450	13.37
9	.022	.040	.052	.129	.0042	.0100	.0137	.0352	9.90

NOTE: Bars numbered 6 and 7 were poured from iron deoxidized with titanium. Bars numbered 8 and 9 are control bars. Iron was not deoxidized.

tests the high phosphorus bars gave best results, as regards rate of growth, while those bars poured from the high silicon mixture were considered most inferior due to excessive cracking as well as a high rate of growth, a new set of high phosphorus bars and a new set of high silicon bars were poured from metal in which a deoxidizer was used.

These bars were poured from the same tap of the cupola. To each ladle of iron 0.25 per cent of titanium in the form of ferro-titanium was added. In order that complete deoxidation might take place, the iron was stirred and held in the ladle as

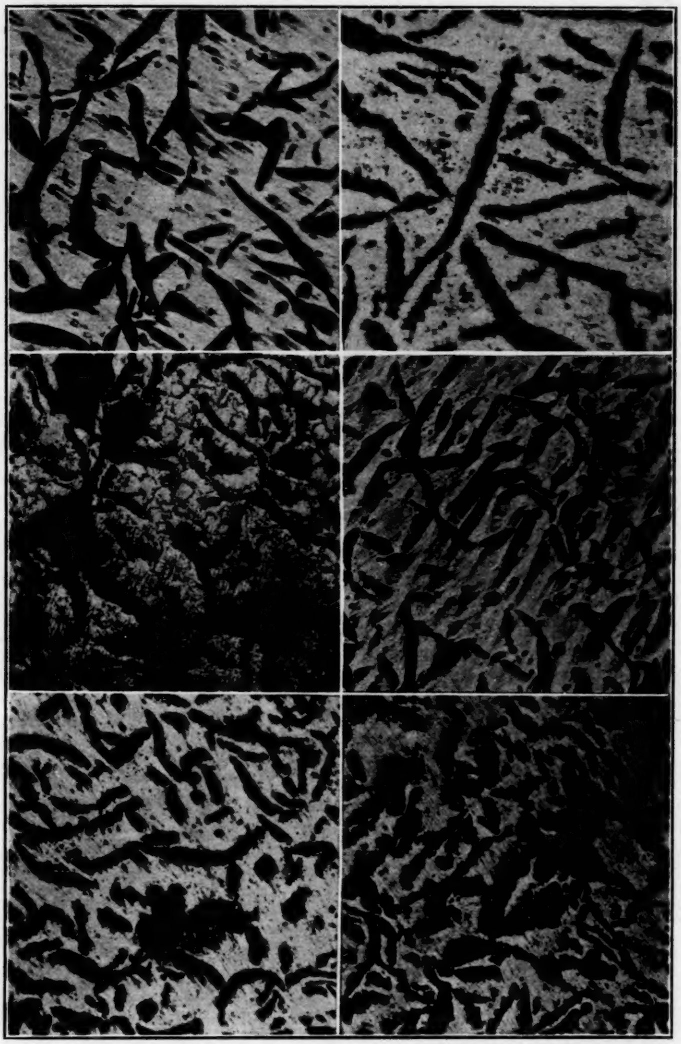

FIG. 1—PHOTOMICROGRAPHS 1 TO 6 ALL UNETCHED MAGNIFIED 100X.—NO. 1 (UPPER LEFT) HIGH SILICON IRON "AS CAST," SHOWING ORIGINAL STRUCTURE—NO. 2 (UPPER RIGHT) HIGH SILICON IRON BAR 1-A AFTER 50 HEATINGS, SHOWING STRUCTURE OF CORE—NO. 3 (CENTER LEFT) HIGH SILICON IRON BAR 1-A AFTER 50 HEATINGS, SHOWING STRUCTURE NEAR SURFACE—NO. 4 (CENTER RIGHT) LOW SILICON IRON "AS CAST," SHOWING ORIGINAL STRUCTURE—NO. 5 (LOWER LEFT) LOW SILICON IRON AFTER 50 HEATINGS, BAR 2-A SHOWING STRUCTURE OF CORE—No. 6 (LOWER RIGHT) LOW SILICON IRON AFTER 50 HEATINGS, BAR 2 SHOWING STRUCTURE NEAR SURFACE OF BAR.

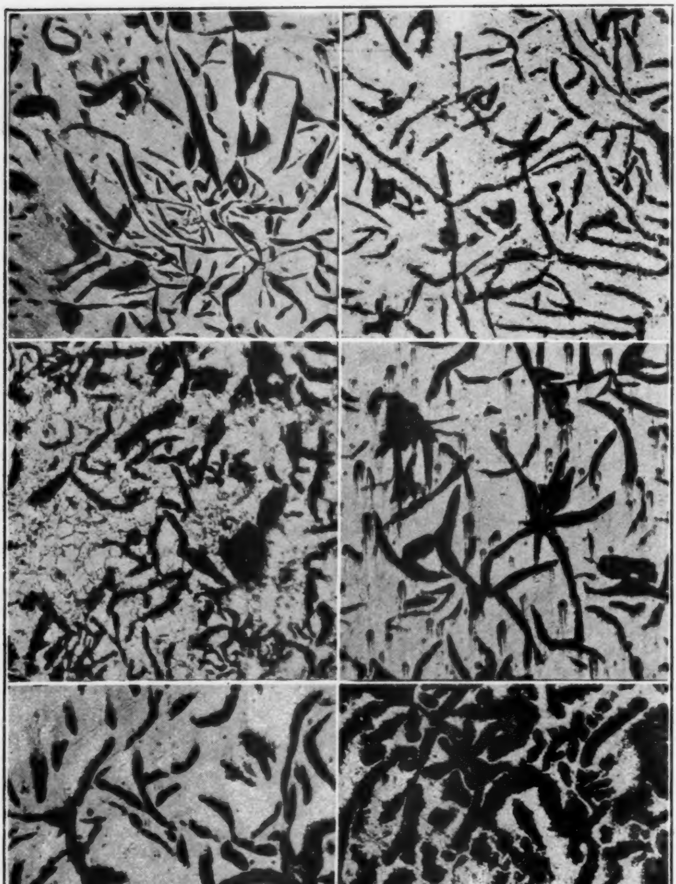

FIG. 2—PHOTOMICROGRAPHS 7 TO 12 ALL UNETCHED MAGNIFIED 100X—NO. 7 (UPPER LEFT) HIGH MANGANESE IRON "AS CAST," SHOWING ORIGINAL STRUCTURE—NO. 8 (UPPER RIGHT) HIGH MANGANESE IRON BAR 3-A AFTER 50 HEATINGS, SHOWING STRUCTURE OF CORE—NO. 9 (CENTER LEFT) HIGH MANGANESE IRON BAR 3-A AFTER 50 HEATINGS, SHOWING STRUCTURE NEAR SURFACE—NO. 10 (CENTER RIGHT) HIGH PHOSPHORUS IRON "AS CAST," SHOWING STRUCTURE OF ORIGINAL BAR—NO. 11 (LOWER LEFT) HIGH PHOSPHORUS IRON BAR 4 AFTER 50 HEATINGS, SHOWING STRUCTURE OF CORE—NO. 12 (LOWER RIGHT) HIGH PHOSPHORUS IRON BAR 4-A AFTER 50 HEATINGS, SHOWING STRUCTURE NEAR SURFACE OF BAR.

long as possible. It was then carefully skimmed and the bars poured. Two control bars in which the iron was not deoxidized were poured from the same heat.

The composition of these bars is given in Table 3.

All bars were then machined, measured and heated as in the

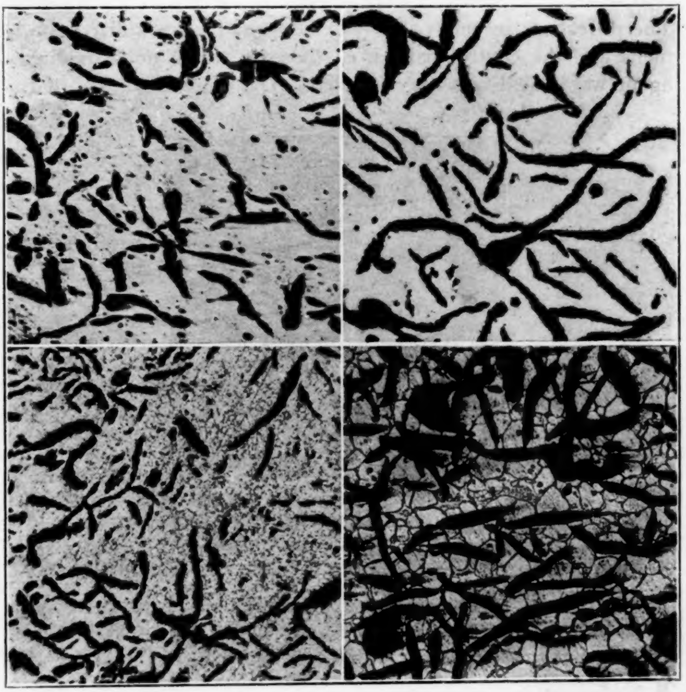

FIG. 3—PHOTOMICROGRAPHS 13 TO 16—NO. 13 (UPPER LEFT) NICKEL-CHROMIUM IRON "AS CAST," SHOWING ORIGINAL STRUCTURE, UNETCHED—NO. 14 (UPPER RIGHT) NICKEL-CHROMIUM IRON BAR 5 AFTER 50 HEATINGS, SHOWING STRUCTURE OF CORE, UNETCHED, X100—NO. 15 (LOWER LEFT) NICKEL-CHROMIUM IRON BAR 5 AFTER 50 HEATINGS, SHOWING STRUCTURE NEAR SURFACE, UNETCHED, X100—NO. 16 (LOWER RIGHT) HIGH PHOSPHORUS IRON AFTER 50 HEATINGS, SHOWING STEADITE ENVELOPE AROUND GRAINS OF IRON, ETCHANT 2% HNO_3, X100.

previous experiments, except that the work was stopped after the 25th heating.

Results are as shown in Table 4.

Discussion of Results

All bars tested grew less than the bars of similar composition in the first series of experiments at the end of 25 heatings. The difference in rate of growth between the deoxidized specimens and the control bars, i. e., those to which no deoxidizing agent was added was very marked. The results indicate that a

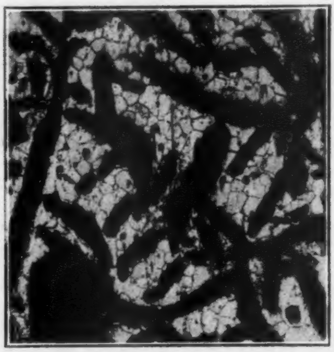

FIG. 4—HIGH SILICON IRON AFTER 50 HEATINGS, SHOWING GRAIN STRUCTURE, ETCHANT 2% HNO_3, X100.

strong deoxidizing agent such as titanium has a powerful effect in retarding growth.

The high phosphorus bars again showed the slowest rate of growth, but this difference was much less than in the first series of experiments.

Photomicrographs

The photomicrographs show the effect of heating on the irons used in the first series of experiments. The "as cast" structure is given in each case for comparison with the structure near the surface, and in the core of the bars after 50 heatings. The structure of the bars near the surface is in all cases greatly altered.

The structure of the iron in the core shows some alteration in all cases except that of the high phosphorus iron (11 of Fig. 2).

Photomicrograph 16 of Fig. 3 shows the large amount of steadite in the core of the high phosphorus iron. It will be noted that the steadite envelopes the grains of ferrite. This may be compared with 17 of Fig. 4 which shows the grain structure of the high silicon iron. In this case there is no steadite "envelope."

FIG. 5—HIGH PHOSPHORUS IRON "AS CAST," SHOWING STEADITE "LAKE," ETCHANT 2% HNO_3, X500.

Conclusions

As a result of the work described in this paper the following conclusions were reached:

1. Of the irons tested, the high phosphorus iron had the slowest rate of growth.

2. An iron deoxidized with titanium grows much more slowly than a cupola melted iron of the same composition, but without the titanium addition.

As an explanation of these observed phenomena the authors suggest the following:

1. The steadite in high-phosphorus iron (see photo-micrographs 16 and 18 of Figs. 3 and 5) forms an envelope around the grains of iron. This steadite envelope has the effect of slowing down the rate of penetration of the gases which cause growth.

2. If growth be due, as is commonly held, to the action of oxygen or other gases; in a deoxidized iron, the growth must all be caused by gases which penetrate from the exterior of the casting and not caused, in part, by gases already in the iron. For that reason the rate of growth of a deoxidized iron would be slower than that of an iron which was not deoxidized.

Acknowledgment

The authors wish to express their thanks to Mr. Robert Wallace, foundry superintendent of the National Cash Register Company, who furnished the bars used in these experiments.

Heat and Scale Resisting Cast Irons

By Oliver Smalley, New York

Regarded from a strictly metallurgical point of view cast iron is an intermediate between an unrefined and a refined product. In its broad application, it is remelted pig iron and it is this complex ferrous substance which science and art have endeavored to understand and control without involving the costly processes necessary in the manufacture of the finally refined product, steel. The metallurgy of cast iron, unfortunately has been complicated so long by the unrestricted permission of the use of the name "Cast Iron" to any product having a ferrous base melted in the cupola, whether it be made from hot, medium or cold blast pig iron, steel, scrap or old tin cans, that it has become identified as a cheap material rather than as a metallurgical product possessing specific and advantageous properties. That such a state of affairs has been allowed to prevail comes about from the fact that this rude complex material has a use. Because of the severe service conditions demanded today, and the precise specifications of the modern engineer, its place in industry is diminishing and is being taken by materials whose properties are specific, under control, and meet the more rigidly enforced service conditions.

The diminishing field of cast irons, despite their low price, may be found in almost every branch of endeavor. Constructional, railroad, locomotive, automobile, electrical, mechanical, and agricultural engineering industries are turning to steel and special alloys. The chill iron roll is giving way to the superior chromium molybdenum steel roll; chemical and heat resisting castings are being replaced by costly nickel chrome alloys, steel castings and forgings; hydraulic cylinders and rams, steam cylinders, pumps, etc., are being made in ordinary and special alloy steel castings; heat treating and tempering pots, antimony and lead refining pans are now manufactured in steel and alloys, while the car wheel is losing its place to a manganese treated steel wheel.

A moment's thought on the basic position of cast iron shows that this encroachment by superior materials has not only manifested itself over a number of years, but that it is to continue as long as the iron founder permits its present identification and as long as the engineer is allowed to recognize it as the cinderella of metallurgy.

Part 1—High Duty Castings

Resistance to growth on heating and cooling, ability to withstand sudden changes of temperature without cracking, hot strength, superior and consistent physical properties, toughness and resistance to wear, are the most prominent problems engaging the manufacture of high duty castings. Centering around the quantity and physical form of the graphite, progress can be measured from present understanding of the chemico-physical reactions involved during graphite formation; from the information available on the behavior and effect of graphite under any given set of conditions, and from the cost of any process necessary to effect any desired result.

Thus measured, we are confronted by a situation where developments have still to emerge from an overwhelming mass of irreconcilable technical and scientific data and researches, and where prejudices of the past have yet to give way to the advances of science. It is well established, however, that the more nodular the form of the graphite and the more stable the carbides under heat conditions, everything else being equal, the better is cast iron able to resist the heat and stress conditions demanded of high duty castings, and that the ideal cast iron would be a material possessing the advantageous properties conferred by the presence of free graphite in conjunction with those of the finally refined product, steel. To this end development of superior cast iron has been directed.

Cold blast and synthetic pig irons that are free from the vagaries of fluctuation and uncertain chemical composition and structural heterogeneity of modern hot blast furnace irons, afford obvious and well recognized advantages. They offer a starting point which facilitates the manufacture of a material to uniform

and consistent physical properties, and places cast iron in line with true alloys.

The Place of Semi-Steel

Because of the high cost of special pig irons, attention was next directed to the use of steel as a corrective of the varying graphite and structural uncertainties of low grade pig irons. Among the first to publish material on this important advance in cast iron metallurgy was David McLain. Since his original work, many others, including Campion, Field and Cameron, have contributed to the knowledge of this hybrid material and because of its merits, its identification in the high duty cast iron field is increasing. At the same time, the susceptibility of steel to oxidize during melting and the limitations of the cupola as a melting unit, together with the general disregard of adequate control, are such as to place a certain limited and restricted field on semi-steel. All steel, semi-steel and cold blast pig iron melted in the cupola under identical conditions to give the same resulting composition as far as total carbon, silicon, manganese, phosphorus, and sulphur are concerned, have a different structural composition, physical properties and behave differently in service. It is the author's experience that this difference is attributable to occluded gases, the chemical form of the sulphur compounds and to mechanically suspended ferrous oxide. It is this contamination which renders semi-steel a close grained and consequently stronger material. At the same time semi-steel lacks the low coefficient of friction, the resilience and ability to withstand sudden changes of temperature of ordinary cast iron. The practice of melting steel in the cupola—like all other methods which can cheapen cost—is too apt to be regarded as an end in itself rather than as a means to an end. It is for this reason that instead of regarding it of value as a corrective in the manufacture of a superior product when made under precise control, many founders still regard its use as one of the pitfalls of successful production.

Following McLain's use of steel, the next advance was made by J. E. Johnson, Jr., who endeavored by means of a bessemer

converter to blow out the silicon from one portion of his charge so that oxygen was made to enter it, which he claimed to be impossible if more than a small quantity of silicon were present. To this blown metal he added pig iron straight from the furnace and thereby restored the silicon of the whole to any desired amount without removing the oxygen. By this process, he claims to make up an iron to any desired precise composition and properties. This new oxygen carrying cast iron (if ever it made its debut in practice) has not survived despite the superior claims made for it.

Numerous other attempts have since been made in the direction of the application of a steel making process, refining sufficiently for the production of castings free from plates of graphite. Of the most recent, the Thyssen-Emmel and Wüst processes are of interest although they have yet to be established industrially. The former claims a special modification of the working of an ordinary cupola wherein the coke consumption is less than in normal practice and where a total carbon content of less than 3.00 per cent is assured in the finished casting. Silicon is used to effect the desired graphite separation. The Wüst process involves the use of a newly designed furnace comprising a vertical shaft which is filled from above with the charge of iron and necessary fluxes to be melted. At the base of the shaft a small open hearth furnace is constructed. Melting is performed by means of an oil burner using preheated air. It is claimed that the oil fuel necessary amounts to about 10 per cent of the weight of iron melted.

Advances in Foundry Processes

Parallel with these metallurgical and furnace advances, progress has been made in what might be termed foundry processes.

In a fundamental research published by the author it was shown "that there exists for every grade of ordinary cast iron a minimum rate of cooling during solidification which yields within practical limits the same grain or density regardless of the section or dimension of the casting." The superior properties, accom-

panying irons where the rate of cooling and chemical composition have been adjusted so as to procure the desired nodular form of graphite, are well established and open up a potential field in the foundry industry. There is, however, a distinct difference between the service value of castings under heat influences where the desired structural form of graphite has been secured by means of rapid cooling of soft irons and where it has been secured by retarded cooling of hard irons. The photomicrographs of

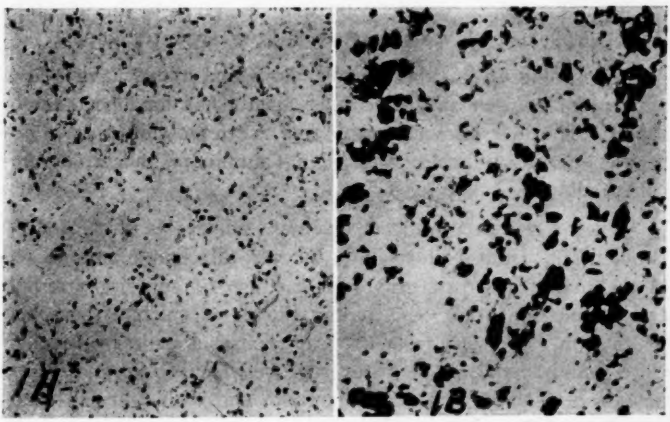

FIG. 1—(A), PHOTOMICROGRAPH OF A CASTING MADE IN IRON MOLD, BEFORE HEAT TREATING. (B), PHOTOMICROGRAPH OF SAME CASTING AFTER HEAT TREATING AT 920 DEGREES CENT. A AND B BOTH 50 MAGNIFICATIONS

Fig. 1 representing a casting having an analysis of total carbon 3.20, silicon 2.34, manganese 0.62, phosphorus 0.88, and sulphur 0.06 made in a long life iron mold, before and after heating to 920 degrees Cent. (1688 degrees Fahr.) show that growth is not eliminated when the graphite no longer presents a continuous path for the penetration of oxidizing gases and that stability of the carbides by the use of low silicon irons, or alloy additions, is of the highest importance. It is for this reason that the hot mold process using white or mottled iron exploited by Lanz offers significant opportunities.

In contradistinction to processes involving rate of cooling as a principal factor in controlling the disposition of the graphite, are those which by the use of special metals, alloys or chemical graphitizers aim to eliminate rate of cooling during solidification as an important factor in the process and thereby obviate the disadvantages of altered casting arrangements and the use of hard baked molds. A paper[1] on the value of special metal ladle additions of copper, nickel, aluminum, tungsten, chromium and molybdenum and other metals, in this direction was published by the author when consideration was also given to the possibilities of producing malleable cast iron direct from the cupola.

The value of silicides, silicon alloys and alloys having high affinity for oxygen as graphitizing agents has long been established. The best known graphitizers are ferro-silicon, calcium-silicide, titanium-silicide, magnesium, aluminum and zirconium-silicon alloys.

So far as can be traced, calcium-silicide was first used by Wohler and Hans Goldschmidt. Later, Meehan experimented in the manufacture of gray iron castings of superior strength and greater uniformity, by adding silicide of calcium to molten white iron. Physical tests of gray irons so made by Meehan were found by the author to average between 40,000 and 57,000 pounds per square inch tensile strength and with a brinell hardness from 240 to 300.

Influence of Graphitizers

To ascertain the relative influence of ferro-silicon, calcium-silicide, magnesium-silicon and zirconium-silicon alloys on the hardness, graphitization and tensile strength, a series of tests were made on a white iron of the composition, total carbon, 2.6; silicon, 0.90; phosphorus, 0.15; manganese, 0.30, and sulphur, 0.06.

The composition of the calcium-silicide alloy used was 25 per cent calcium, 55 per cent silicon, 5 per cent iron; the ferro-silicon was 50 per cent silicon, the magnesium-silicon alloy had

[1] Proceedings of the Institute of British Foundrymen, 1922-23.

12 per cent magnesium, 40 per cent manganese and 40 per cent silicon; and the zirconium-silicide alloy had 35 per cent zirconium, 45 per cent silicon, and 20 per cent iron.

Each alloy was crushed into small pieces less than .20 of an inch and added in the ladle. The method of mixing and the time of standing to alloy thoroughly, and the temperature of casting were identical for each test.

All test pieces were cast in green sand molds. Square bars ⅜, ½, ¾, 1, 2 and 3 inches were made to determine mass in its effect on hardness and graphitization. Tensile test bars were cast .75 of an inch in diameter and machined to .630 of an inch in diameter. Brinell tests were made on one face of each of the square test bars after removing .03 of an inch by grinding. Fracture examination was made through the center of each bar.

Before treatment, the iron when cast into bars 6 inches by 3½ inches by 3½ inches was white throughout. The results of the ladle additions are detailed in Table 1.

One per cent calcium-silicide alloy addition enables the casting of ¾ of an inch square bars uniformly gray. Less than ¾ of an inch the bars present white corners and edges and offer machining difficulties. Less than ⅜ of an inch the bars are white throughout.

With 1 per cent ferro-silicon, 2 inch square bars are uniformly gray; 1 inch square bars present white corners and edges, while the ½ inch bar is entirely white.

With 0.50 per cent calcium-silicide in conjunction with 2.5 per cent ferro-silicon, the casting of .25 inch square bars of uniformly gray iron was possible.

With 0.50 per cent magnesium-silicon alloy in conjunction with 0.25 per cent ferro-silicon did not prove appreciably more effective than 1.0 per cent ferro-silicon.

With 0.75 per cent zirconium-silicon alloy in conjunction with 0.50 per cent ferro-silicon proved as effective as 1.00 per cent calcium-silicide alloy.

By the term "gray fracture" is meant that fracture ordinarily accepted by the blast furnace and foundry man. This,

Table 1

Cast No.	Per Cent Graphitizer Additions by Weight	1 Inch Square Bars Brinell Hardness	1 Inch Square Bars Fracture	0.75 Inch Square Bars Brinell Hardness	0.75 Inch Square Bars Fracture	0.5 Inch Square Bar Brinell Hardness	0.5 Inch Square Bar Fracture	0.35 Inch Square Bar Brinell Hardness	0.35 Inch Square Bar Fracture
0	Ordinary white iron; no additions	477	White	483	White	483	White	483	White
1	1.0 Calcium-Silicide	228	Gray	241	Gray	302	Corners and edges white, center gray	364	White
2	1.0 Ferro-Silicon	286	Corners edges white, center gray	331	Mainly white, center gray and speckled white	364	White	375	White
3	0.50 Calcium - Silicide and 2.50 Ferro-Silicon	228	Gray	228	Gray	235	Gray	241	Gray
4	0.50 Magnesium-Silicon and 2.50 Ferro-Silicon Alloy and 0.25 Ferro-Silicon	239	Corners white, rest gray	364	Mainly white, center gray	418	White	477	White
5	0.75 Zirconium-Silicon Alloy and 0.50 Ferro-Silicon	223	Gray	235	Gray	321	White speckled with gray	387	White

*Before treatment, a bar six inches by 3½ inches by 3½ inches, cast in sand was white throughout. The calcium series present a sparkling gray fracture; the ferro-silicon series a similar type of fracture but lighter in color; while the zirconium series present a peculiar dark gray velvety fracture; indicative of great toughness.

however, inadequately describes the fracture of gray irons. White iron rendered gray by ferro-silicon additions, presents a light colored gray fracture somewhat similar to that obtained from semi-steel. Calcium-silicide results in a gray fracture that might be compared with foundry pig iron No. 2; while zirconium-silicide causes a dark gray fracture that might almost be termed black, and which gives the appearance of extraordinary toughness, a property later confirmed by impact tests.

The superior tensile strength of gray iron made from graphitized white iron, Table 2, confirms Meehan's findings and sets new standards in tensile strength with suitable machining qualities. These demonstrate the potentialities of such irons for

Table 2

Effects of Graphitizers on the Tensile Properties of White Cast Iron

Cast No.	Per Cent Graphitizer by Weight	Per Cent Silicon in Finished Casting	Tensile Strength Pounds per Square Inch	Physical Condition
"A"	0.50 Calcium-Silicon Alloy (25 per cent Ca) (55 per cent Si)	1.0	53,060	Each bar as cast 0.75 inches diameter
"A"	0.50 Calcium-Silicon Alloy (25 per cent Ca) (55 per cent Si)	1.0	67,437	Annealed 800 degrees Cent. 5 minutes and allowed to cool over 3 hours
1	1.00 Calcium-Silicide	1.48	47,140	Each bar as cast 0.75 inches diameter
2	1.00 Ferro-Silicon (50 per cent Silicon)	1.24	61,184	Each bar as cast 0.63 inches diameter
3	0.50 Calcium-Silicon and 2.50 Ferro-Silicon	2.30	38,403	Each bar as cast 0.63 inches diameter
4	0.5 Magnesium-Silicon and 0.26 Ferro-Silicon	1.25	52,029	Each bar as cast 0.63 inches diameter
5	0.75 Zirconium-Silicon Alloy and 0.50 Ferro-Silicon	1.56	48,117	Each bar as cast 0.63 inches diameter

high duty purposes. Because of the form of graphite and because of the control of graphitization, eliminating rate of cooling as an important factor, such a process offers advantages over that necessitating the use of hot molds, where uncertain graphitization may result in crystal weakness, machining difficulties and cracking on sudden changes of temperature. Both processes offer the same advantage in resisting growth when subjected to repeated heating and cooling.

Part 2—Chilling Irons

Where the combined properties of both white and gray irons are required in the same casting, cast iron becomes possibly the

most complex and least understood of any metallurgical product. No fundamental advances can as yet be claimed and any progress in the development of superior gray irons for high duty purposes finds little application to either the car wheel or chill roll.

Chill Car Wheels

The ability of the cast iron car wheel to withstand severe sudden changes of temperature in service is second only in importance to a hard wearing surface. Due to the complexity of the mold into which poured, casting strains are encountered in the car wheel, which render it unsuitable for service. By pitting the wheels at approximately 1650 degrees Fahr. after casting, these strains are somewhat relieved or removed.

To determine the efficacy of this annealing process and the ability of the iron to withstand severe changes of temperature in service, the "thermal test" is applied. This test is made by pouring a ring of molten iron around the chill tread of the wheel. The severity of the test varies with different railroad companies' specifications, but commonly if a wheel is found broken in pieces, or if any cracks in the plate extend through or into the rim after pouring a 2 inch section of metal around the wheel, in 2 minutes or under, all wheels of the same tap as the wheel under test are rejected.

The more highly strained the wheel after pitting, the sooner does cracking occur on test, hence any condition conducive to a good thermal test without affecting the service life of the wheel is desirable.

The variation in composition of 1040 wheels that have given average service or better is:

Total Carbon	3.0	to	4.10	per cent
Silicon	.43	to	.95	per cent
Manganese	.30	to	.92	per cent
Phosphorus	.182	to	.480	per cent
Sulphur	.092	to	.230	per cent

The average chemical analysis of these wheels is: Combined carbon .30, graphite carbon 2.82, total carbon 3.42; silicon .63, manganese .54, phosphorus .319, and sulphur .151.

In a highly competitive field, the car wheel maker aims to meet both the physical and chemical specifications of the railroad by the use of as little pig iron as possible, melting with as low a coke ratio as will bring his metal down and by driving the cupola to maximum capacity.

The average metal mixtures comprise 80 to 100 per cent old wheels, 0 to 20 per cent pig iron, 9 to 10 per cent steel. For the manufacture of superior wheels, where severe service conditions have to be met special mixtures are used, including the use of larger quantities of pig iron, or pig iron of superior quality or even charcoal pig iron. This latter is favored where extra severe thermal test is enforced.

Variations of chill are corrected in the ladle, by the addition of steel or ferro-silicon. If the metal is on the soft side, steel scrap is used; ferro-silicon when the chill is high. Some car wheel makers introduce small additions of crushed ferro-manganese to each car wheel ladle. Whether this is to correct an oxidized condition of the steel, to facilitate machining or to increase solidity, the car wheel maker is not certain. The common contention is that it exerts an all-round beneficial effect. Why charcoal or superior pig iron should enable a wheel to withstand a severer thermal test and why the all scrap wheel made under the similar conditions should be stronger, have a closer grain and present a lighter colored fracture, but fail more readily under thermal test, is also a matter for conjecture.

In Table 3 details of four wheels offering exceptional contrast are given. Wheel No. 1 was made to meet an extraordinarily severe thermal test. This wheel was returned after several years of service. On breaking, it presented a dark gray fracture; wheel No. 4 made in the ordinary way failed badly on thermal test and presented a light gray sparkling fracture on breaking.

The chemical analyses show:

1. That the total carbon and graphite contents are the highest and the combined carbon and sulphur contents lowest in the special wheel.

2. That the total carbon and graphite contents are lowest and the combined carbon and sulphur contents highest in the wheel that failed quickest under thermal test.

3. That there is nothing in the chemical composition of wheel No. 3 to explain its low thermal test.

Physical Examination

Structurally, car wheel iron may be compared with ordinary carbon tool steel. The essential difference is that a car wheel, except at the tread, is interlaced by tiny flakes of graphite which occupy approximately 7 per cent of the total volume. Thus, rapidly cooled car wheel iron presents the same susceptibility to spontaneous cracking on sudden heating as hardened tool steel, while well annealed iron may be subjected to severe thermal stress without any risk of cracking.

Table 3

Details of Four Tested Car Wheels

Wheel	C.C.	G.C.	T.C.	Si.	Mn.	P.	S.	Fracture	Comments
1	.28	3.33	3.61	.69	.81	.286	.110	Black Gray	Withstood severe thermal test. Returned from service. Chill worn thin.
2	.40	3.13	3.53	.73	.53	.273	.142	Dark Gray	Withstood standard thermal test. Returned from service. Chill worn thin.
3	.66	2.84	3.50	.66	.86	.361	.138	Light Gray	Passed thermal test unsatisfactorily. Cracked in 2 minutes 5 seconds with loud report.
4	.68	2.78	3.46	.69	.90	.374	.178	Light Gray Sparkle	Failed thermal test. Cracked in 1 minute 5 seconds with exceptionally loud report.

Because the crystal formation of pearlite is a true indication of the efficacy or otherwise of an annealing process and because its formation can be readily ascertained, we have at our disposal a simple means to not only measure and control the annealing process after casting, but also to study in what way the nature of any combination of irons differs from any other combination, and the effect of different cupola conditions on any particular mixture. In other words, a simple metallographic examination offers a direct means to control pitting scientifically and also to

understand and follow the physical changes that accompany any new set of conditions whether metallurgical or foundry.

One other essential difference between the microstructure of tool steel and car wheel iron is the presence of phosphide of iron eutectoid (a hard brittle material of low melting point, 1755 degrees Fahr.), which occupies about 3 per cent of the whole volume of the iron. Exerting an embrittling effect on cast iron it renders car wheels more susceptible to cracking under thermal test.

Photomicrographs of Car Wheel Irons

The photomicrographs of Figs. 2 to 5 portray the microstructure of each wheel at a magnification of 200 times. Special wheel, No. 1, photomicrograph of Fig. 2 displays a matrix of well marked laminated pearlite, small quantities of phosphide eutectoid uniformly distributed and graphite flakes long, thin and intermingling.

This structure is common to that of soft gray irons designed to withstand sudden changes of temperature without cracking. It is, however, the converse of what is desired in a tough, dense, hard wearing iron.

Normal wheel, No. 2, photomicrograph of Fig. 3 reveals a matrix of laminated pearlite that does not display so marked a separation of the carbide and ferrite as special wheel No. 1. The laminations, however, are sufficiently well marked as to indicate complete annealing after casting; the form of the graphite flakes is similar to wheel No. 1 except that they are not so long and continuous or present in such large quantities.

The photomicrograph of wheel No. 3, low thermal test, is displayed in Fig. 4. The carbide matrix is sorbitic. Pearlitic formation can be traced, but the quantity present is infinitely small. Another structural difference displayed by this wheel is the short, stubby, inclined to be curly form of the graphite.

The photomicrograph of wheel No. 4, rejected on thermal test, displayed in Fig. 5, shows structural features common to those of wheel No. 3. The carbide is a little more pearlitic al-

though the majority is distinctly sorbitic, while the graphite has the same stubby form.

These four illustrations suitably chosen from a number in an endeavor to correlate the structural disposition of the micro-

FIG. 2 FIG. 3

FIG. 2—PHOTOMICROGRAPH OF SPECIAL WHEEL NO. 1—X200
FIG. 3—PHOTOMICROGRAPH OF NORMAL WHEEL NO. 2—X200

constituents and the physical properties, explain the superior thermal properties of wheels Nos. 1 and 2; show the reason of the dark gray fracture presented by wheels Nos. 1 and 2 and of the cause of the light gray sparkling fractures of wheels Nos. 3 and 4; and explain the superiority of wheels Nos. 3 and 4 under the drop test. Incidentally they lightly touch on the vexed prob-

lem of the difference between hot and cold blast pig irons; the relation of fracture to chemical composition; the difference between cast iron and semi-steel; and finally throw light on the anticipated comparative behavior of high duty irons made from

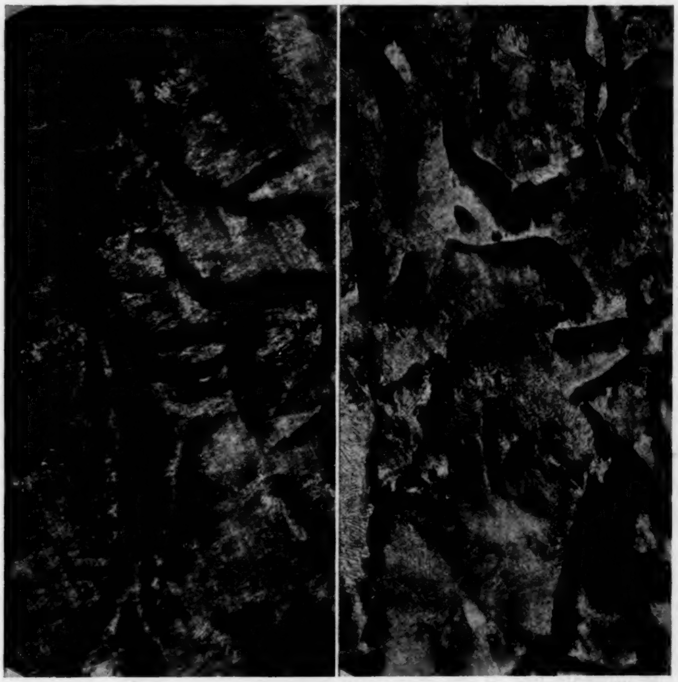

FIG. 4 FIG. 5

FIG. 4—PHOTOMICROGRAPH OF LOW THERMAL TEST WHEEL NO. 3—X200
FIG. 5—PHOTOMICROGRAPH OF WHEEL NO. 4 REJECTED ON THERMAL TEST—X200

high grade pig rich mixtures and those made from low grade white iron and graphitized, when subjected to rapid heating and cooling in service.

The explanation offered for the superiority of special wheel No. 1, under thermal tests, is that not only was the chemical

composition such as to permit a freer deposition of graphite and a free separation of the carbide eutectoid (pearlite), into its component parts cementite and ferrite, but that because of the greater purity of the irons used (rich pig mix) and melting in the first few charges, there was less oxygenation and gaseous contamination than obtained in wheel No. 4, for example, which was cast from the last few tons of a melt (scrap and steel) of over 220 tons, when the cupola was emitting deep brown oxide fumes from the stack.

Part 3—Scale Resisting Cast Irons

The lack of information on cast iron to withstand high temperature under oxidizing conditions, its uncertainty in service and the encroachment of costly heat resisting alloys into the cast iron field is the justification for reference to this phase of the subject.

White Iron Castings

White irons made in the cupola, open hearth, or electric furnace are comparable, provided fundamental conditions of melting are observed and practiced. The cupola furnace which manufactures at the lowest cost is most widely favored. The abuse of this simple metallurgical unit, and the tendency to operate without adequate metallurgical control, however, are responsible for difficulties of control of composition, of temperature effects, of unsoundness and of such variation in the quality of the finished product, that the immediate monetary advantages of any reduced cost of the molten metal must needs be considered in relation to the ultimate life of the casting in service.

The mechanism of breakdown of ordinary white iron under heat oxidizing conditions proceeds as follows:

1. Dissociation of the carbides.
2. Loss of carbon at surface.
3. Oxide formation at surface.
4. Migration of carbon from center to surface.
5. Growth of the iron by repeated heating and cooling.
6. Loss of carbon from center.

7. Penetration of oxide between adjacent crystal grains.
8. Formation of oxide cavities and collapse.

Were it not that this breaking down process eliminated the natural brittleness and fragility, white iron would lose much of its serviceable value for high temperature work; hence malleability, although indicative of the first stage of collapse of the iron under heat influences, is a necessary property gained only at the expense of an equally important one, viz.: Resistance to scaling. Therefore, any element in manufacture which adversely affects one or the other property is to be avoided, while any improvement or advance must necessarily improve the scale resisting powers without affecting robustness in service.

Chemical Specification

(1) *Carbon*

Before white iron scales, the carbon must first burn away from the outer edges. It would seem, therefore, that the higher the carbon content the longer the life of the iron. This would be true if all the carbon remained in the combined condition as carbide, but the higher the total carbon content, the sooner the deposition of free carbon (graphite) on annealing, everything else being equal. As this free carbon is readily combustible, and burns away leaving in its stead enlarged cavities, and later oxide as shown by the photomicrograph of Fig. 6 we have a direct contradiction of the first premise. To consider the quantity of carbon, therefore, without a knowledge of its stability as a carbide and constitution, may be more misleading than instructive. It may be safely stated, however, that the higher the carbon, the longer the life, providing the graphitization period is not decreased; in other words, the advantage of an increased carbon content can only be assured by suitable adjustment of the other elements present.

(2) *Silicon*

Favoring the formation of graphite and readily oxidizing to silica, silicon is an undesirable element so far as longevity under the direct influence of temperature is concerned. Conferring

toughness, reducing liquid shrinkage on solidification, and being the most economical natural deoxidant, only such quantities as enable solidity of casting and promote deposition of graphite at such a rate as will confer the desired toughness without accelerating oxidation, should be present.

(3) *Manganese*

Carpenter and Reegan[2] show that with a constant carbon of 2.4 per cent and manganese ranging from .51 to 1.6, 151 heatings

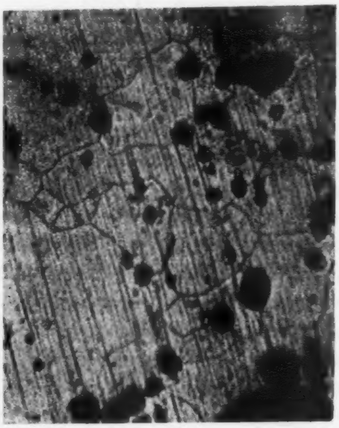

FIG. 6—PHOTOMICROGRAPH OF IRON HEATED WITH GRAPHITE CARBON HAVING BURNED AWAY LEAVING LARGE CAVITIES

caused a volume increase of 7.49 per cent in the .51 per cent manganese bar. With .935 per cent manganese the same treatment produced an increase of 3.10 per cent and with 1.6 per cent manganese 151 heatings produced no change in volume.

A. Levi, discussing cast iron subjected to repeated heats and coolings at temperature not exceeding 900 degrees Cent. (1652 degrees Fahr.), states that "In the manufacture of heat resisting cast iron it is desirable in practice to obtain in particular:

[2] Carpenter and Reegan, Journal Iron and Steel Institute, 1911, No. 1.

"A high manganese or chromium content, these elements forming stable carbides which resist annealing. These carbides are of the type (Fe Mn) 3 C. Their stability retards increase of volume subsequent to the first heat." Campion considers carbides of manganese are more resistant to heat than the corresponding compounds of iron. Manganese, therefore, plays an important part in preventing growth and loss of strength when the iron is subjected to high or fluctuating temperature conditions. The graphitizing influence of silicon is partially counteracted by manganese. Besides functioning to promote stability of the carbide, manganese is an efficient deoxidizer and cleanser, and neutralizes the influence of sulphur.

(4) *Sulphur*

Sulphur exists in cast iron in three forms, as sulphide of manganese, sulphide of iron and organic sulphur.

The stability of the carbon as carbide, hence the resistance to scaling and growth, is a function of the quantity of sulphur that crystallizes with the carbide. Because of the powerful effect of sulphur in this direction and because of the preferential affinity of manganese for sulphur, forming an inert material, it would appear that high sulphur and low manganese would be more desirable in scale resisting castings than a low sulphur and high manganese. Making cast iron tender at a red heat, causing quicker solidification and under certain conditions blowholes and dirty irons, its presence is undesirable. It is considered that .01 per cent sulphur will neutralize 15 times as much silicon.

(5) *Phosphorus*

Rendering iron more brittle under shock, reducing the strength hot, accentuating the deposition of graphite, and because of its tendency to segregate, phosphorus must be under rigid control. Making metal more fluid and thin, reducing its melting point and decreasing contraction, it has this in its favor.

(6) *Gases*

While exerting a profound influence, there is no reliable information on the quantity or the form gases take or of their

ultimate effect on the physical properties and behavior of the iron in service. The work of Johnson, Oberhoffer, Piwowarsky, Jominy, Ekman and Jordan on this subject is well known. It is established that irons melted under oxidizing conditions have distinctive and different properties from those melted under reducing conditions, everything else being equal; but a method of estimating correctly the quantity and form of the various gases existing in cast iron still remains to be found. Although we have definite proof that iron melted with any excess of air takes a higher chill, possesses a finer grain, is more fragile and brittle hot, has greater strength and toughness at ordinary temperatures in the absence of any mechanical defects, no evidence exists that oxygen as such is the cause.

Heat Tests

To obtain more specific and comparative information on (1) the relative effects of the various elements; (2) the best combination of elements of white iron for high temperature work; and (3) the effect of different melting conditions, a series of test slabs were cast from cupola melted iron in green sand to the form shown by Fig. 7.

Any adhering sand was removed and the iron slabs accurately ground. The slabs were then heated in an oil fired muffled furnace under oxidizing conditions to a temperature averaging 1600 to 1700 degrees Fahr. for 14 days continuously, arranging to cool each to a black heat in open air as quickly as possible every day and then to replace immediately, in the hot furnace.

(a) *Effect of Carbon*

The chemical composition of the irons and appearance of fractures are detailed in Table 4.

Under impact test slab No. 1 proved most brittle and No. 3 the best able to withstand shock. The per cent loss by scaling and appearance of fracture after tests are listed in Table 5.

These show best results as far as scaling was concerned obtained from the 3.01 per cent carbon iron, although No. 3 yielded the toughest iron.

(b) *Silicon*

Four castings of the composition given in Table 6 were used to investigate this element.

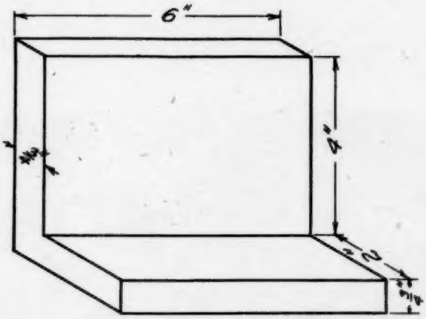

FIG. 7—SKETCH OF TEST SLAB USED IN HEAT TEST

Table 4

Chemical Composition Test Slabs and Appearance of Fracture

No	Total Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Phosphorus Per Cent	Sulphur Per Cent	Fracture
1	2.70	.52	.23	.192	.165	White
2	3.01	.55	.33	.376	.169	White
3	3.67	.58	.19	.184	.184	White

Table 5

No.	Total Carbon Per Cent	Loss by Scaling Per Cent	Fracture
1	2.70	30.2	Slightly mottled.
2	3.01	28.3	More mottled than No. 1.
3	3.67	29.2	Mottled a little more than No. 2.

Under impact test, the resistance to shock increased as the silicon content although none was exceptionally brittle.

In their relative capacity to resist oxidation on heating, the test bars did not display any real difference. The scale was very adherent to No. 3 but easily removed from No. 6.

Table 6

Analyses of Castings Used in Test to Investigate Effect of Silicon

No.	Total Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Phosphorus Per Cent	Sulphur Per Cent	Fracture
4	3.01	.55	.33	.376	.167	White
5	3.174	.66	.34	.380	.165	White
6	3.270	.79	.32	.364	.210	White
7	3.261	.98	.35	.400	.198	White

The explanation of the apparent similarity to resist scaling is found from photomicrographs of Figs. 8 and 9 representing irons Nos. 4 and 6, respectively. These photographs were taken from the central zone of each specimen. Except for the presence of a few pit holes and a slight dissociation of the carbide

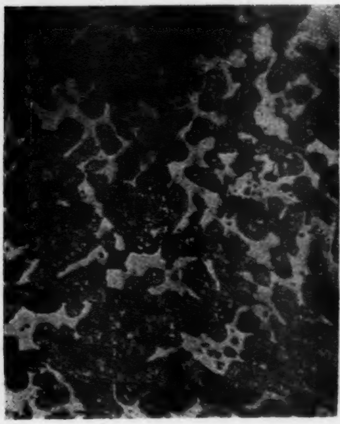

FIG. 8

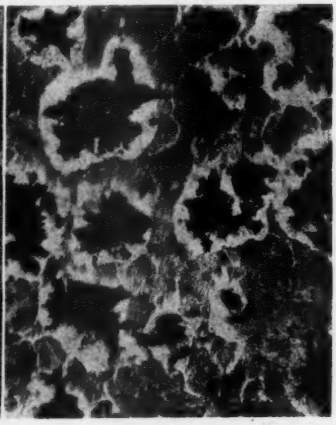

FIG. 9

FIG. 8—IRON NO. 4 OF HEAT TEST—MICROGRAPH OF CONTROL ZONE OF SPECIMEN—X150

FIG. 9—IRON NO. 6 OF HEAT TEST—MICROGRAPH OF CONTROL ZONE OF SPECIMEN—X150

the structure of the .55 per cent silicon iron is unchanged. The carbon content of this zone is about 2.20 per cent. The photomicrograph of Fig. 9 shows that the effect of the increased silicon content has been to cause precipitation of patches of graphite (shown as black), which are surrounded by ferrite (pure iron).

The matrix is carbide containing approximately .80 per cent carbon. The total carbon content of this zone may approximate 1.60 per cent.

The deposition of graphite in this specimen followed by subsequent oxidation has caused the iron to swell, and for this reason the scaling test is somewhat misleading. It is obvious, however, that in actual service this iron will have a shorter ultimate life than the lower silicon iron.

It may be concluded that:

(1) .55 per cent silicon resists oxidation better than the higher silicon irons, presuming the castings are uniformly solid.

(2) Where toughness, because of the method of handling, is essential and where casting difficulties are encountered, the

Table 7

No.	Silicon Per Cent	Loss by Scaling Per Cent	Fracture
3	.55	28.3	Outer edge ⅛-inch crystalline, remainder just turning mottled.
4	.66	28.1	Outer edge 3/32-inch crystalline, remainder distinctly mottled.
5	.79	28.1	Outer edge 3/32-inch crystalline, remainder a little more mottled than No. 4.
6	.98	29.0	Outer edge ⅛-inch crystalline, remainder fine gray.

higher silicon series are preferred, but the silicon content should not exceed .80 per cent.

(3) The silicon content should vary in inverse proportion to the section of the casting.

(c) *Manganese*

Thus far low manganese and high sulphur irons have been used for test purposes, and although each is beneficial in increasing the stability of the carbide, yet they neutralize each other in this respect. It was decided therefore to employ low sulphur irons and thus eliminate the effect of the sulphur as far as possible.

Details of composition and appearance of the fracture of each iron are given in Table 8.

A striking effect of the manganese was the refining influence on the outer zones of the metal in immediate contact with the scale. In the low manganese iron the edges are coarse and crystalline, exhibiting bright facets. As the manganese content increases this band is reduced in dimension and the texture becomes finer until at 3.00 per cent it is almost silky. It was also observed that as the manganese content increased, the scale was less adherent.

Table 8

Data of Irons Used in Test to Show Effects of Manganese
Chemical Analyses and Fracture

No.	Total Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Phosphorus Per Cent	Sulphur Per Cent	Fracture
7	2.93	.66	.28	.32	.083	White
8	3.06	.73	.65	.40	.076	White
9	3.06	.63	1.18	.33	.074	White
10	3.32	.82	2.27	.35	.068	White
11	3.12	.74	2.97	.34	.059	White

Resistance to Scaling and Appearance of Fracture After Test

No.	Manganese Per Cent	Loss by Scaling Per Cent	Fracture
7	0.28	28.1	Outer edge 1/8-inch crystalline, center just turning mottled.
8	0.65	29.3	Outer edge 1/8-inch less crystalline than No. 7, center mottled.
9	1.18	30.2	Outer edge 7/64-inch less crystalline than No. 8, center mottled dark color.
10	2.27	30.5	Outer edge 3/32-inch very fine texture, center as No. 9, a little darker color.
11	2.97	30.2	Outer edge 3/32-inch like fracture of hardened tool steel, center black color.

The order of toughness after the scaling treatment was:

Iron No.	Manganese Content
7	0.28 per cent
11	2.97 per cent
8	0.65 per cent
10	2.27 per cent
9	1.18 per cent

These results show that while manganese may be beneficial in reducing or preventing the growth of gray irons subjected to repeated heating and cooling and that while quantities of up to 1.50 per cent are considered advantageous in such castings as superheaters and fuel economizer headers, Diesel engine parts, lead and antimony pots, special stoker and grate parts, etc., there

is no advantage to be gained from the use of manganese in either low sulphur or high sulphur white irons.

It may be concluded from the above tests that manganese:

1. Reduces the resistance to scaling.
2. Increases graphitization.
3. Decreases strength, and that this element should not be allowed to exceed .30 per cent.

(d) *Phosphorus*

The compositions of irons made to investigate the effect of phosphorus are shown in Table 9.

The fall in strength and increased brittleness accompanying a rising phosphorus content are indicated by the transverse test results listed in Table 10.

Under impact tests, irons Nos. 18, 19 and 20 proved so brit-

Table 9

Chemical Analyses and Fracture of Test Iron to Show Effect of Phosphorus

No.	Total Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Phosphorus Per Cent	Sulphur Per Cent	Fracture
15	2.94	.49	.24	.198	.153	White
16	3.12	.62	.24	.310	.176	White
17	3.06	.58	.27	.700	.182	White
18	2.85	.68	.24	1.81	.211	White
19	2.55	.56	.22	2.73	.220	White Dull
20	2.20	.55	.21	3.41	.233	White Dull Amorphous

Table 10

Effect of Phosphorus

No.	Phosphorus Per Cent	Transverse Strength Pounds	Deflection in Inches
15	.198	4,410	.11
16	.310	3,670	.10
17	.700	3,390	.10
18	1.810	3,320	.09
19	2.730	3,020	.08
20	3.41	2,320	.04

Table 11

Effect of Phosphorus on Scale Resisting Properties

No.	Phosphorus Per Cent	Loss by Scaling Per Cent
15	0.198	28.2
17	0.700	26.3
18	1.810	27.0
19	2.73	38.0
20	3.41	63.0

tle that in the presence of such quantity of phosphorus, white iron is quite unsuited for any purpose where ordinary strength and rigidity are required.

Table 11 shows that the adherence of the scale diminished as the phosphorus content increased.

The toughness after the scaling treatment was similar in irons Nos. 15 and 16. Iron No. 17, while more brittle than irons Nos. 15 and 16, was sufficiently tough for ordinary service conditions. Nos. 18, 19 and 20 were brittle.

These tests show that phosphorus in normal quantities common to ordinary scrap iron is not detrimental. When present in excessive quantities it exerts a marked influence. The exact nature of this influence is not clearly shown by the scaling tests, for the failure of irons Nos. 19 and 20 is not due alone to rapid oxidation but to the adverse effect of phosphorus on the strength of the iron hot. It is for this reason rather than because of excessive scaling that phosphorus must be avoided. Where the service temperature reaches 1600 degrees Fahr. 0.50 per cent is the maximum quantity permissible for ordinary purposes; where 1650 degrees Fahr. is reached .35 per cent is a safe maximum; and where a temperature of 1700 degrees Fahr. is encountered .20 per cent should not be exceeded.

(e) *Sulphur*

Three casts were made with sulphur; .083 per cent, .167 per cent and .326 per cent. Details of chemical composition and appearance of fracture as cast are given in Table 12.

When correctly melted and poured suitably hot, the liquid shrinkage and general soundness of each iron were satisfactory. If oxidized or poured cold, high sulphur caused unsoundness and excessive drawing on solidification.

Under impact test alloy 14 proved most brittle.

The microstructure at the central zone of the scale test slab after 14 days' continuous heating is shown in Fig. 10. This is very similar to what it was before heating. The carbon content was about 2.6 per cent.

Table 12

Chemical Analyses and Fracture Appearance of Test Irons to Show Effect of Sulphur

No.	Total Carbon Per Cent	Silicon Per Cent	Manganese Per Cent	Phosphorus Per Cent	Sulphur Per Cent	Fracture
12	2.93	.66	.28	.32	.083	White
13	3.00	.55	.33	.376	.167	White
14	3.02	.51	.26	.37	.326	White

Table 13

Effect of Sulphur on Scale Resisting Properties
Scaling Test

No.	Sulphur Per Cent	Loss by Scaling Per Cent	Fracture
12	.083	28.1	Mottled
13	.167	28.0	Slightly mottled.
14	.326	25.3	White

FIG. 10—MICROGRAPH OF CENTRAL ZONE OF SCALE TEST SLAB AFTER 14 DAYS' CONTINUOUS HEATING—X150

In that high sulphur has reduced scaling some 3 per cent, it is beneficial; in that it embrittles and that this excessive brittleness is not removed after long annealing, it is detrimental. For this reason excessively high sulphur should be guarded against, although where heavy sections and severe oxidizing conditions are encountered, it has exceptional value. For general purposes a sulphur content of 0.20 per cent is recommended.

Oxidized Iron

The drops of iron in their descent over the incandescent coke of the tuyers region of the cupola may be oxidized to a greater or lesser degree, determined by the nature of the irons melted, the coke to iron ratio, the blast pressure and the speed of melting.

Increasing the stability of the carbides under heat influences, enabling a deeper chill, white irons made under strongly oxidizing conditions have these advantages. The disadvantages are: Rendering control of chemical composition uncertain; inducing a weak crystal structure and high liquid shrinkage which causes excessive cracking in manufacture; increasing the susceptibility of the iron to fracture on sudden heating and cooling; and being responsible for both surface and internal mechanical defects. The above advantages are more than offset by the disadvantages.

As modern tendency is directed towards cheapening the cost of castings rather than establishing and selling to a predetermined service guarantee, average cupola practice inclines towards oxidizing conditions. Oxygenation, however, despite its far reaching and potential influences, is a factor rarely considered. It is not uncommon to hear of claims made concerning successful melting using a 1 to 10, 1 to 12, or 1 to 14 coke to iron ratio, but investigation invariably reveals that the saving in coke is more than absorbed by the increased expenditure of irons. Foundries, using all scrap mixtures, have been known to offer bonuses to their superintendents on coke saving, a pernicious practice that often succeeds in increasing the number of bad castings, waste metal and ladle repairs.

The most baneful effects of oxidized conditions of melting manifest themselves in both chilling and white irons.

To demonstrate practically the effect of an oxidizing condition on the heat resisting properties of white iron, a series of test slabs were made, varying the degree of oxygenation by increasing the blast pressure, using light scrap and reducing the quantity of coke. The extent of oxygenation was measured by the color of the fumes from the cupola stack which varied from a light gray to a deep red.

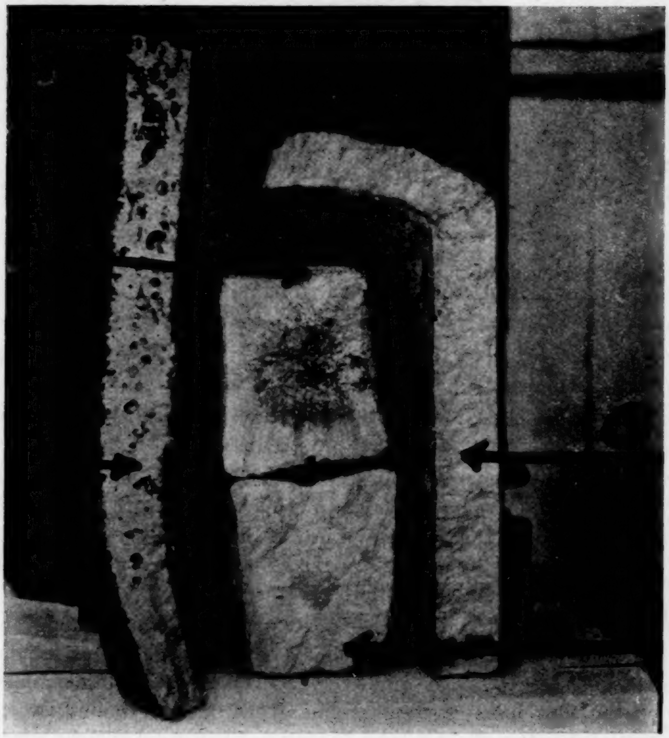

FIG. 11—DRAW TEST BARS AND NORMAL AND OXIDIZED METAL—A AND B, DRAW TEST BARS—C, NORMAL METAL—D, OXIDIZED METAL

(a) *Draw Tests*

Under correct melting conditions, the liquid shrinkage of this iron on solidification approximates 1.3 per cent. When deep brown fumes are pouring from the cupola stack, it is 6.3 per cent. The marked effect of slight differences in the degree of oxygenation exhibited by the fracture of the sample draw test bar is shown in Fig. 11. These specimens represent iron melted under satisfactory conditions when the fumes of the stack were

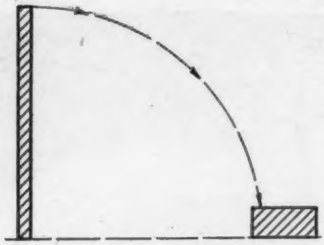

FIG. 12—SHOWING METHOD OF TESTING BRITTLENESS IN RELATION TO OXIDATION, CASTING TEMPERATURE AND RATE OF COOLING

free from red color and the other when reddish brown fumes were omitted.

The brinell test failed to reveal any difference between the hardness of correctly melted and oxidized irons.

Brittleness increased in direct relation to oxidation, casting temperature and rate of cooling. This was measured by allowing a plate 1 inch thick and 24 inches long to fall from the vertical through an angle of 90 degrees on to the edge of a cast iron block as represented in Fig. 12.

Under similar conditions of casting temperature and rate of cooling, metal correctly melted could not be broken by the dropping test, whereas oxidized metal broke readily, sometimes on the first fall. Casting strains from uneven cooling, weak crystal structure from casting too hot and too rapid cooling, exert an equally embrittling influence on both the correctly and incorrectly melted metal.

(b) *Scaling Tests*

Sections through the test slabs on scaling show that because of the general unsoundness of those cast from oxidized metal, and because of the presence of mechanically contaminated oxide, any comparison of the relative loss of scaling is unfair, for in some places the severely oxidized slabs were almost eaten through, and wherever an oxide inclusion existed on the outer surface of the casting, this was sufficient to start a local attack

which rapidly penetrated the mass. The general appearance of the normal, medium, and strongly oxidized metal after scaling tests are shown by the cross section etchings A, B. and C of Fig. 13. Where the sections of the test slabs made from oxidized metal were not pitted or otherwise unsound, the loss from scaling was 3 to 4 per cent greater than that of the ordinary melted metal. The more rapid loss of carbon from the oxidized metal is

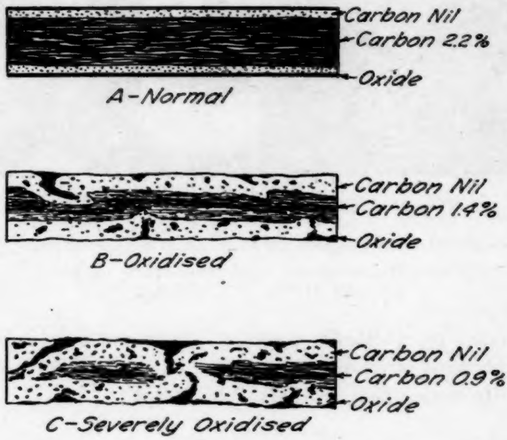

FIG. 13—SKETCHES OF CROSS SECTIONS OF SCALING TEST PIECES—A, NORMAL METAL—B, OXIDIZED METAL—C, SEVERELY OXIDIZED METAL

apparent from the increased thickness of the carbon free zones in immediate contact with the scale shown by etchings B and C of Fig. 13, while the photomicrograph of Fig. 14 shows the center zone of the oxidized slab to contain less than .90 per cent carbon. The black patches in this photograph surrounded by a white border is contaminated oxide. The photomicrograph of Fig. 15 shows an oxidized iron in the last stages of collapse after the scaling test.

It may be concluded that any practice conducive to oxidation, unless corrected by subsequent treatment either in the ladle

FIG. 14 FIG. 15

FIG. 14—PHOTOMICROGRAPH OF CENTER ZONE OF OXIDIZED SLAB

FIG. 15—PHOTOMICROGRAPH OF OXIDIZED IRON IN LAST STAGES OF COLLAPSE AFTER THE SCALING TEST

or by duplexing, creates a condition which not only impairs the general physical properties of the iron, but materially shortens its service life under heat oxidizing conditions.

Discussion

Chairman R. S. MacPherran: Mr. Smalley's paper is very interesting and contains a great deal of new material. This matter of high test cast iron which is referred to in the first third of his paper is one of vital interest to the gray iron men, because we have to get either higher cast iron or else we will lose our business to the steel people. If we can get 50,000 pounds and over, we will have a very much better cast iron than we have ever had before.

E. M. Handley: What is the chemical reaction that takes place when the calcium silicide is added to the ordinary gray iron, and is that a cupola mixture or a white iron mixture such as is used in malleable?

O. Smalley: The chemical reaction that takes place on the addition of the alloys referred to, is not absolutely clear. In my early work, I believed that the graphitization took place because of the increased purification of the iron, and that by removal of suspended oxides it was

possible to get a freer deposition of graphite. This has since been confirmed. At the same time, purification alone does not explain the remarkable graphitization that results from the use of the earthy metals when in combination with silicon. Such gas tests as have been made lead to the view that the graphitization results from the chemical change of the dissolved gases in the molten iron. There is no information on the catalytic effect of these alloys.

The high test results are representative of what is obtained from either cupola or air furnace iron.

Progress in the Production of High-Test Cast Iron*

By Dr. E. Piwowarsky,† Aachen, Germany

Translated by Dr. Richard Moldenke, Watchung, N. J.

Great progress has been made these last years in Germany in the development of gray cast iron. Apart from the effects of an increased competition on the world market, in which American electrically-made castings particularly fought very strongly against the German, this development is due to the greater emphasis put upon metallurgy in the foundry industry during recent years; for it is probably not accidental that the more recent progressive processes or inventions have originated with metallurgists.

When I discuss the problem of quality in gray cast iron in what follows, this is done principally in connection with the history of its development in Germany. None the less, I do not wish to convey the impression that I have forgotten the progress made in other countries, notably in England and America, where well known metallurgists have also worked with high ambition and great success.

Existing Specifications

If we observe the specifications for strength as given in Table 1—these already corresponding to stricter requirements of more recent purchasing specifications—we notice that grades of cast iron are already regarded as "high-test" which show a tensile strength of from 25,600 to 37,000 pounds per square inch, and a bending strength‡ of 39,800 to 49,800 pounds per square inch. But these figures represent values which every fairly managed foundry can attain without difficulty in the regular run of work.

While some of the prominent foundries were already able one or two decades ago to produce high-test cast iron with a

*Presented on behalf of the Verein Deutscher Eisengiessereien (German Foundrymen's Association).
†Professor of Metallurgy, Technical High School, Aachen, Germany.
‡Confer footnote of Table 1 for meaning of bending strength.

bending strength of 64,000 pounds per square inch—material which later microscopical examination showed to be of a purely pearlitic structure; and while, moreover, P. Goerens[1] had already shown in 1906 that if cast iron of greatest strength were wanted, a pearlitic structure should be aimed for; yet in most cases the foundry manager placed his confidence more particularly in the skill of his practically trained foreman, rather than upon the results of a greater emphasis laid upon metallurgic-scientific

Table 1

SYNOPSIS OF SPECIFICATIONS FOR STRENGTHS OF HIGH TEST CAST IRON

Source of Specifications	Tensile Strength, Pounds per Square Inch	Bending Strength,* Pounds per Square Inch	Deflection in Inches
Bureau Veritas, 1914	25,740	......	....
German Navy, 1913	......	48,360	0.39
German State Railways	25,600 to 37,000	......	....
German Association for Testing Materials and Cast Iron Pipe Manufacturers Society	......	48,360	0.39
German Lloyd	......	48,360	0.39
Holland, 1911	25,600 to 59,730	(41,000)	....
Rumanian State Railways	22,750 to 25,600	......	....
Swiss Federal Railways	25,600	......	....
American Society for Testing Materials	27,900	(76,800)	0.12
		(48,650)	0.09

Figures given in parentheses have been calculated from minimum bending requirements.

*Translator's Note: The term "bending strength" as used by Dr. Piwowarsky apparently has the same meaning as the more usual term "modulus of rupture." The modulus of rupture is the value given by applying the standard formula for flexural stress to the load at rupture (P) and span (l) and cross section of bar. If S_B denotes this "bending strength" or "modulus of rupture" and d is the diameter of a round specimen loaded at the middle of the span then

$$S_B = \frac{8Pl}{\pi d^3}$$

In obtaining the results given, in all probability the German standard test bar was used. This is 30 millimeters in diameter, 650 millimeters long, and is broken on supports 600 millimeters apart. The deflections and bending strength given are probably taken from this bar.

direction. Those foundries, however, in which the existing status of metallurgic science had been properly utilized, and who consequently could produce high grade castings, did not see the immediate necessity for publishing their operating methods and thus deprive themselves of an advantage.

[1] The Constitution of Pig Iron, *Stahl und Eisen*, 1906, p. 397.

"Pearlitic Cast Iron" Starts Publications

It was only when the treatises of K. Sipp[2] and A. Diefenthaeler[2], in which the word "pearlitic" as applied to cast iron was coined, become generally known did there appear a flood of

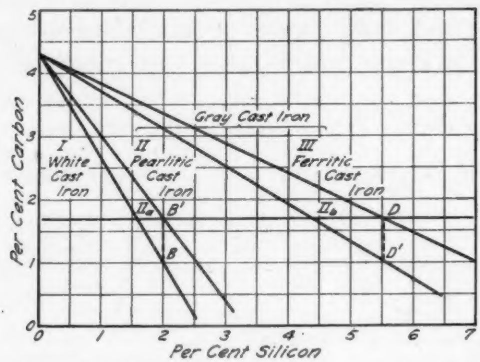

FIG. 1—CAST IRON DIAGRAM—SUBJECTED TO THEORETICAL CONSIDERATION (MAURER)

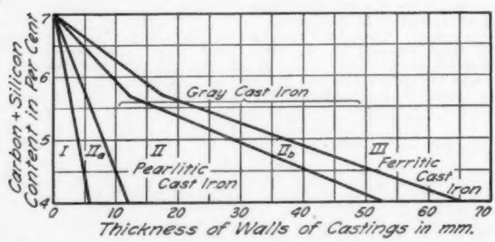

FIG. 2—EFFECT OF WALL THICKNESS OF CASTING UPON CHARACTER OF THE IRON (DIAGRAM ACCORDING TO GREINER—KLINGENSTEIN)

literature on the subject, both from practical and scientific aspects, but mainly in reaction against a too liberal interpretation of the patents on pearlitic cast iron[3], and to confine them to their

[2] Cf. *Reports of the Materiolprüfungsant zu Berlin-Dahlem*, 1922, No. 40, p. 318.
[3] German Patents: No. 310913, May 10, 1916; No. 325250, Oct., 1918; No. 417689, Jan. 23, 1926.

proper basic idea—namely, the systematic pre-heating of the mold in conjunction with a correspondingly suitable mixture—and to show that there are other ways and means of producing high-test cast iron with a preponderance of pearlitic structure.

The publication of Maurer's cast iron diagram (Fig. 1), and of the high figures of strength for gray cast iron[4] reached by Krupp; the publications of K. Emmel[5] on his high-test, low total carbon cupola iron (Thyssen-Emmel); the graphic interpretation —with resemblance to Maurer's cast iron diagram—of the relations between thickness of section on the one hand, and silicon and carbon percentages on the other (Fig. 2) by Greiner and Klingenstein[6]; all these and many other similar publications and communications have shown that suitable operating methods were already in existence which allowed structural control of the metal matrix, and that with a pearlitic matrix structure alone, the high-test characteristics of gray cast iron was by no means guaranteed. It was generally recognized that the Lanz pre-heated mold method was the ideal solution of the special problem of particularly complicated castings involving greater resistance to growth phenomena under higher temperature ranges, as also the high-test characteristics of that material. The novelty of the method was questioned but in few instances.

The development of lines of better structural control of the metallic matrix could really only go either by way of lowering the silicon, or lowering the total carbon. They are fundamentally partially dependent upon the formerly prevalent uncertainty of structural control in ordinary, normally constituted grades of iron. Whence came this uncertainty?

Causes of Uncertainty of Facts

It is well known that a high silicon percentage, as well as a high total carbon favor the rapidity of carbide decomposition, and only recently this well known fact was proven quantitatively by Oberhoffer and Piwowarsky in connection with dilatometric investigations.[7]

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[4] *Krupp's Monatshefte,* 1924, p. 115.
[5] *Stahl und Eisen,* 1925, p. 1466.
[6] *Zeitschrift des Vereins deutscher Ingenieure,* 1926, p. 387.
[7] Cf. *Stahl und Eisen,* 1925, No. 28, p. 1173.

A high silicon as well as a high carbon content accelerate the disintegration of cementite just below the melting point (region of rapid rates of disintegration), i.e., the iron becomes effectively graphitized. Graphite and temper-carbon, however, dissolve comparatively slowly in iron, and (at least in the early stages) partially as elementary carbon. Both the above conditions, however, at low degrees of superheat and too rapid setting of the metal, favor a graphitized product (commencement of graphite crystallization, cessation of phenomena attending a retardation of solidification below freezing temperatures). With increasing degrees of superheat, however, the particles of undissolved graphite* present in the melt disappear more and more, increasing quantities of carbide molecules are probably formed in the melt, and the iron sets with constantly whiter fracture; as in the region of rapid rates of disintegration of carbide, directly after setting the necessary crystallization tendency is diminished (cf. crystallization diagram, Fig. 29). This is why it is possible to succeed in getting irons of the same composition and under equal rates of cooling to set with either a gray or a white fracture, as desired. In Fig. 3, I have given such an instance, using an iron with no silicon and about 3.00 per cent carbon (Swedish charcoal iron with its carbon reduced by scrap additions). The above discussed fact, taken however in connection with the formerly prevailing considerably lower melting and pouring temperatures, is undoubtedly the principal reason for the then existing inability to obtain reliable results; as also the observation that conflicting opinions existed until recently concerning the

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*Translator's Note: Graphite Nuclei: It is very important to an understanding of portions of this paper to have a conception of the meaning of the phrase "graphite nuclei." The late Professor Heyn states that in changing from the liquid phase to the solid, crystalline phase, crystals are formed which originate from individual points which are called crystallization centers by Tamman. These may be invisible—at any rate they first become visible when minute crystals attach themselves and form visible and coarser balls of crystals called *Kerne* by Tamman (confer Martens-Heyn: Materlienkunde II A).

Piwowarsky designates these crystallization centers "Kerne" or "Seeds" (germination points for starting normal crystallization). The designation "Kerne" has been translated to "Nuclei." Piwowarsky holds that molten cast iron contains graphite nuclei in suspension, which—as the metal freezes or "sets" from the starting point of coarse graphite crystals. When, however, abnormal temperatures of superheating are attained, these graphite nuclei go into solution in the molten metal, and as this cools and comes to freezing, there are no crystallization starting points for coarse graphite and the graphite is precipitated in a state of very fine division with attending benefits—as explained in his paper.

A B C

FIG. 3—A, HEATED TO 2,200 DEGREES FAHR. IN VACUUM FOR ONE-HALF HOUR; NOT ETCHED; X100. B, SAME AS A BUT ETCHED; X250. C, HEATED TO 2,640 DEGREES FAHR. IN VACUUM FOR ONE-HALF HOUR; ETCHED; X100. ALL SPECIMENS COOLED IN THE FURNACE.

effect of the pouring temperature upon the quality and hardness of the product.

Hailstone[8] as well as Honda and Murakami[9] found a distinct percentage reduction in graphite with rising pouring temperatures up to about 2600 degrees Fahr., while Northcott[10], for instance, found the reverse to occur with the range of 2230 to 2570 degrees Fahr. The relation between chemical composition and structural development is naturally affected—on occasion very far-reachingly—by the conditions of operation, mixture-making and temperature. As a consequence possibly many of the more recently developed relationship deductions may not have unlimited validity. This may extend possibly even to Maurer's as well as the Greiner-Klingenstein diagrams.

Two Solutions Offered

There were two ways of getting over the specified difficulty, ways which—often unconsciously perhaps in structural-scientific relation—were, nevertheless, the outcome of good practical observation. The first way was the reduction of the rate of carbide disintegration during the melting operation by the use of irons low in silicon in the mixture. Thus the melting iron might be capable of directly dissolving a maximum of undecomposed iron carbide as such, and hence need not take up much elementary carbon. Since, however, a low silicon iron can of itself dissolve more carbon, in consequence of the formation of a smaller proportion of silicides, any existing amounts of graphite and tempercarbon are taken up in it far more quickly, and converted into the carbide molecular form corresponding to the equilibrium of temperature resulting from the presence of both kinds of molecules. In this manner a greater homogeneity of the liquid phase is obtained, and in consequence thereof a more uniform relation between chemical composition and physical structure of the solidified iron. In this manner of proceeding, however, the rate of cooling must be artificially retarded, i.e., the elimination of a part of the silicon in its action upon the rate of disintegration of

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[8] Hailstone: *Carnegie School Mem.*, 5 (1913), p. 51.
[9] *Science Report Tohoku Univ.*, 10 (1921), p. 272.
[10] *Foundry Trade Journal*, 29 (1924), p. 515.

the iron carbide during the setting of the iron must be compensated for by the pre-heating of the molds to differently high degrees. There is an advantage to this method, however, in that a cast iron is produced which exhibits an increased resistance to "growing" at high temperatures. Lanz has systematically followed this direction, and it has been brought to its full fruition by the investigations of K. Sipp and A. Diefenthaeler.

The same objectives, by the second method, were attained by reducing the total carbon and thus bringing about a lower rate of iron carbide disintegration before actual fusion. Iron carbide is much more stable when in dilute solution, and the possibility of temper-carbon formation during the melting process is restrained. The molten solution will, accordingly, be homogenized more rapidly here also, any existing graphite and temper-carbon particles be dissolved more quickly, and the structural dependence of the solidified matrix of the gray cast iron upon the mixture will show more dependable correlations in accuracy of results and smaller sensitiveness to changes in section.

This method, evidently the basis of the Thyssen-Emmel process, has the advantage that in consequence of the higher silicon content it is not necessary to artificially retard the rate of cooling, and it is possible to make use of mixtures suited to rates of cooling existing under ordinary room temperatures in foundries. Because of the reduction in the absolute graphite content, there also results an appreciable improvement in the physical properties of the resulting cast iron. K. Emmel has succeeded in completely overcoming all the difficulties arising in producing a low total carbon cast iron of sufficient temperature and highest quality in the cupola under normal operation, and pouring into successful work. A series of analyses and physical strength results of "high-test" cast irons made by the Thyssen-Emmel process are given in Table 2.

Table 2

TENSILE STRENGTHS AND ANALYSES (EMMEL)

Heat No.	Diameter of Bar in Inches	Tensile Strength, Pounds per Square Inch	Average Composition, Per Cent				
			Total Carbon	Si.	Mn.	P.	S.
1	0.787	44,375	2.84	1.96	0.84	0.13	0.140
1	0.787	44,090					
1	0.787	45,800					
1	0.787	45,800					
2	0.591	53,760	2.53	2.44	0.90	0.13	0.170
2	0.394	50,350					
2	0.581	54,190					
3	0.591	53,190	2.62	2.09	0.96	0.15	0.111
3	0.591	55,040					
3	0.591	44,800					
4	0.591	59,170	2.70	2.20	1.35	0.20	0.130
4	0.591	59,025					
4	0.591	59,025					
4	0.591	58,455					
5	0.787	45,370	2.66	1.90	0.74	0.26	0.140
5	0.787	46,080					
5	0.787	46,080					
5	0.787	46,080					
5	0.787	43,520					
5	0.787	42,240					
5	0.787	34,990					
6	0.787	41,100	2.51	2.20	0.83	0.18	0.105
6	0.787	45,940					
6	0.787	43,240					
6	0.787	41,960					
7	0.787	45,660	2.48	2.31	1.07	0.18	0.164
7	0.787	42,240					
7	0.787	45,660					
7	0.787	44,945					
8	0.787	41,960	2.69	2.19	0.86	0.11	0.138
8	0.787	41,100					
8	0.787	45,370					
8	0.787	45,370					
9	0.787	46,080	2.80	2.12	1.01	0.13	0.115
9	0.787	45,370					
9	0.787	45,370					
9	0.787	46,080					
9	0.787	40,110					
9	0.787	56,180					
9	0.787	54,760					
9	0.787	54,330					
10	0.787	44,945	2.39	2.70	1.04	0.15	0.122
10	0.787	46,080					
10	0.787	46,080					
10	0.787	49,350					
11	0.787	48,930	2.74	2.59	0.70	0.16	0.114
11	0.787	45,370					
11	0.787	47,930					
11	0.787	45,370					
11	0.787	44,375					
12	0.787	44,375	2.60	3.29	1.33	0.10	0.104
12	0.787	43,665					
12	0.787	45,370					
12	0.787	44,660					

(Concluded on next page)

Table 2—(Concluded)

Heat No.	Diameter of Bar in Inches	Tensile Strength, Pounds per Square Inch	Average Composition, Per Cent — Total Carbon	Si.	Mn.	P.	S.
13	0.787	44,660	2.83	2.06	1.12	0.19	0.078
13	0.787	44,520					
13	0.787	43,520					
13	0.787	43,520					
14	0.787	41,530	2.39	2.73	1.30	0.16	0.074
14	0.787	45,370					
14	0.787	42,670					
14	0.787	44,660					
15	0.787	46,665	2.32	2.82	1.04	0.25	0.106
15	0.787	46,665					
15	0.787	45,370					
15	0.787	46,665					
16	0.787	46,650	2.85	1.94	0.78	0.20	0.114
16	0.787	46,650					
16	0.787	46,510					
16	0.787	44,375					
17	0.787	46,940	2.52	2.38	1.14	0.19	0.082
17	0.787	46,510					
17	0.787	48,070					
17	0.787	46,650					
18	0.787	45,370	2.83	2.07	0.99	0.10	0.100
18	0.787	45,515					
18	0.787	45,370					
18	0.787	45,370					
19	0.787	42,950	2.42	2.68	0.93	0.09	0.088
19	0.787	43,665					
19	0.787	44,520					
19	0.787	45,370					
20	0.787	48,070	2.81	2.19	1.12	0.20	0.085
20	0.787	49,350					
21	0.787	32,140	2.40	2.62	0.65	0.16	0.083
21	0.787	46,650					
21	0.787	44,660					
21	0.787	47,505					
22	0.787	42,240	2.66	2.53	1.38	0.19	0.078
22	0.787	45,660					
22	0.787	45,090					
22	0.787	45,800					
23	0.787	45,940	2.86	2.21	1.27	0.19	0.055
23	0.787	46,225					
24	0.787	48,360	2.85	2.35	1.02	0.14	0.105
24	0.787	47,650					
24	0.787	47,650					
24	0.787	47,650					

Studying the above-described methods in conjunction with the state of the art of founding as it existed five to ten years ago, we see that their origin came, on the one hand, from an uncomfortable lack of precision in getting desired results in the production of gray iron castings; and on the other, that it was most

urgent, in view of the increasing competition in the world market and the sharp rivalry of the steel casting, to discover qualities in cast iron which calm reflection indicate as still latent therein.

Low Melting Temperatures versus Superheating

From a strictly metallurgical standpoint, however, it is unquestionably true that the principal cause of imperfections met with lies in the melting and pouring temperatures used, which are much too low and consequently impair the molecular homogeneity of the heats, are insufficient for a complete solution of graphite and cause the structure of cast iron to become the toy of the most varied operating conditions.

Investigations of E. Piwowarsky

The investigations of E. Piwowarsky,[11] who proved experimentally that the degree of superheating temperatures attained by the molten metal determines the percentage and fineness of the graphite in it, thus represent a distinct advance. He even proved that variable degrees of high superheat in the production of the hard casting for "Malleable" had a distinct effect on the subsequent annealing results.[12] As it could be proven—by laboratory as well as works scale tests—that an extraordinary degree of quality could be attained when operating with high degrees of superheat, and that there was developed a graphite formation which was very fine, for the most part in eutectic or tempercarbon form, a patent was applied for in Germany to cover the systematic abnormal superheating of cast iron in the molten state. (This patent application calls for an added 90 to 360 degrees Fahr. to a previously mentioned turning point temperature, which will be further discussed later on, and which places the temperature range of operations into a region corresponding to 2725 to 3100 degrees Fahr.).[13]

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[11] On the Influence of Temperature upon the Formation of Graphite in Pig and Cast Iron, *Stahl und Eisen*, 1925, p. 1455.

[12] Thermal Superheating, and Its Application to the Conduct of the Malleable Annealing Process, *Stahl und Eisen*, 1925, p. 2009.

[13] Patent Application dated Feb. 21, 1925.

Table 3 gives a series of results obtained at the Esslingen Works, [14] in an oil fired air furnace with preheated blast— therefore running extremely hot. On the other hand, Table 4 presents results obtained with highly superheated cupola metal. At my request, this cupola was operated to give particularly hot metal. The figures will show that it is possible even in the cupola to obtain physical strengths with irons running 2.8 to 3.0 per cent

Table 3

OIL-FIRED (PRE-HEATED BLAST) AIR FURNACE CAST IRON, ESSLINGEN WORKS

Composition in Per Cent					Tensile Strength, Pounds Per Sq. In.	Bending Strength, Pounds Per Sq. In.	Brinell Hardness Number
Total Carbon	Silicon	Manganese	Phosphorus	Sulphur			
3.06	2.04	0.83	0.36	0.021	35,415	63,150	225
3.31	2.40	0.76	0.46	0.055	31,720	54,900	195
2.70	1.66	0.90	0.42	0.077	47,505	77,940	215
2.70	1.67	0.96	0.39	0.074	43,520	77,660	235

Table 4

HOT CUPOLA IRON FROM A FOUNDRY IN HOLLAND

Melt No.	Composition in Per Cent					Tensile Strength, Pounds Per Sq. In.
	Total Carbon	Silicon	Manganese	Phosphorus	Sulphur	
441	2.96	1.69	0.81	Trace	0.08	41,530
437	2.96	1.46	0.79	Trace	0.10	51,910
425	2.73	1.70	0.91	0.40	0.09	50,775
420	3.02	1.64	0.82	Trace	0.08	44,090
436	2.68	1.58	0.78	0.16	0.10	47,080
399	2.91	2.34	1.15	0.15	0.08	47,650
451	2.91	2.07	0.99	Trace	0.09	48,640
403	2.89	2.26	0.82	0.20	0.08	44,800
452	2.82	2.04	0.99	Trace	0.09	44,375
453	2.87	2.14	0.99	Trace	0.09	43,240

in total carbon which hitherto were considered possibly only with irons of that carbon content when melted in the electric or the air furnace.

Favorable Effects of "Duplexing"

K. von Kerpely[15] has recently been able to prove the beneficial effects of subjecting molten cupola metal to a subsequent heat treatment in the electric furnace—or "duplexing" it—at temperatures between 2725 and 3100 degrees Fahr.; and thus

[14] Cf. Klingenstein: On High-Test Gray Cast Iron, *Zeitschrift des Vereins deutscher Ingenieure*, 1926, p. 33.
[15] Cf. *Giesserei-Zeitung*, 1926, No. 2, p. 33.

demonstrate the conspicuous advantages of this abnormal superheating. (See Table 5.) This highly superheated iron, which may be allowed to cool down to any desired pouring temperature, when of proper composition, will set with a pearlitic structure, is less affected by differences in structure due to varying section thicknesses and has a graphite content of finest division and uniformly distributed. Furthermore, the volume change is very small at high temperature ranges.

Table 5

STRENGTH OF HIGH-TEST CAST IRON

Composition in Per Cent				Tensile Strength, Pounds Per Sq. In.	Remarks
Total Carbon	Silicon	Manganese	Phosphorus		
3.18	1.92	1.00	0.42	43,095	
3.08	1.73	0.88	...	43,950	
3.26	1.50	0.81	0.41	35,840	
3.08	2.27	0.99	...	44,660	
3.10	1.66	1.01	...	43,950	
3.00	1.50	1.02	0.43	46,650	Hematite Ore Pig Iron
2.85	1.31	0.85	...	50,920	
3.12	1.55	1.00	0.42	44,660	
3.18	2.00	1.06	0.41	44,660	
2.94	1.55	0.98	...	49,780	
2.96	1.55	1.05	...	53,620	
3.05	1.50	0.93	...	48,930	
3.20	1.90	0.93	0.41	39,400	
3.12	1.69	0.76	...	34,280	
3.20	1.78	0.78	0.45	43,095	
3.20	1.83	0.95	...	39,400	
3.15	1.80	0.80	...	44,660	
3.20	1.69	0.85	0.44	43,095	Pig Iron with 10 to 15 per cent Borings.
3.25	1.73	0.93	...	43,095	
3.15	1.79	0.93	...	41,100	
3.20	1.67	1.01	0.42	47,365	
3.10	1.41	0.78	...	48,070	
2.95	1.64	1.01	...	48,070	
3.12	1.62	0.85	0.43	46,225	

(Concluded on next page)

Theories Developed by Science of Crystallization

Regarded from the standpoint of the science of crystallization the following may be added to the above: It is probably generally well known at the present time that the setting of high total carbon irons within the temperature ranges of increasing retardation of solidification below freezing temperatures, takes place with an increasing rate of temperature drop. That is, the

[18] Cf. *Stahl und Eisen*, 1925, No. 5, p. 144.

Table 5—(Continued)

Composition in Per Cent — Total Carbon	Silicon	Manganese	Phosphorus	Tensile Strength, Pounds Per Sq. In.	Remarks
3.15	1.83	0.94	0.65	45,660	
3.06	1.69	1.01	0.81	46,650	
3.25	1.83	1.00	...	44,660	
3.10	1.73	0.85	0.80	49,780	
3.08	1.77	0.94	0.79	49,780	
2.95	1.78	0.98	0.81	51,490	
3.16	1.97	0.83	0.72	45,660	
3.22	1.83	0.93	0.85	43,095	
3.15	1.69	0.85	...	44,520	
2.85	1.88	0.94	0.68	39,400	
2.80	1.88	0.96	0.68	44,520	
3.20	1.97	0.93	0.77	47,365	
3.10	1.88	0.85	0.82	51,490	
3.12	1.83	0.93	0.77	53,480	
2.96	1.83	0.85	0.80	54,760	Short pieces Pig with
2.98	1.85	0.86	0.78	46,650	10 per cent light Scrap.
3.10	1.88	0.85	0.83	46,650	
3.20	1.92	0.93	0.80	49,780	
3.10	1.88	0.95	...	46,650	
3.05	2.02	0.98	...	46,650	
3.20	2.25	0.90	...	43,810	
3.05	1.83	0.90	0.60	44,660	
3.00	1.97	0.93	0.71	52,625	
2.90	1.97	0.90	0.70	44,660	
3.05	1.97	0.91	0.70	44,660	
2.80	2.10	0.93	...	44,660	
3.10	1.97	0.93	0.63	48,950	
2.70	2.00	0.98	...	43,095	
3.10	1.97	1.04	...	46,650	
3.12	2.15	0.99	0.65	44,660	
3.10	1.81	0.93	0.65	48,070	
3.12	1.79	1.03	0.65	49,780	
3.20	1.88	0.92	0.66	48,070	
3.10	1.70	0.93	0.64	48,930	
3.12	1.78	0.90	...	47,365	
3.08	1.79	0.96	...	46,650	
3.10	1.83	0.90	0.66	47,365	
3.12	1.67	0.85	...	48,930	
2.80	1.80	0.93	...	50,635	
3.10	2.16	0.78	0.67	46,650	
2.88	1.88	0.93	0.65	48,070	
2.90	1.93	0.82	...	46,650	
2.85	1.95	0.87	0.63	50,635	
3.05	1.93	0.93	0.63	48,070	Broken Pig Iron with
3.05	1.93	0.93	0.64	59,880	30 per cent Scrap.
3.12	1.96	0.91	0.64	53,480	
3.04	1.97	0.85	...	50,635	
2.95	1.80	0.90	...	48,930	
2.95	1.83	0.90	0.60	48,070	
3.05	1.80	0.93	0.60	48,070	
2.90	2.11	0.93	0.63	48,070	
2.90	1.88	0.93	0.59	53,480	
3.05	1.83	0.98	0.59	44,660	
3.00	1.88	0.93	0.70	48,070	
3.04	1.77	0.88	0.64	51,490	
3.40	1.92	0.98	0.63	29,160	
3.00	2.20	0.90	...	53,480	
3.04	1.83	1.10	0.66	50,635	
3.08	1.93	0.99	...	50,635	
3.05	1.88	0.98	0.65	49,780	

temperature of freezing (setting) sinks increasingly into the range of rapid spontaneous formation of cementite crystals in the interior. If the chemical composition assures a sufficiently rapid disintegration of the carbide, a breaking up of the metastable eutectic with formation of fine eutectic graphite will take place even under conditions of rapid cooling. This is shown in the chilled cast iron of Schuetz[16] which contains 3.00 to 3.50 per cent silicon. Otherwise the iron would set white in fracture. As I had been able to demonstrate—by laboratory tests and practical works' studies—that an increasingly marked subdivision

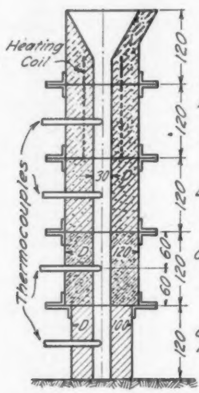


FIG. 4—ARRANGEMENT OF MOLD SHOWING CHARACTER OF SECTIONS

of the graphite *also* takes place, under conditions of equal and even very slow rates of cooling, as the degree of superheat increases, I suspected that dissociation phenomena (of the iron carbide), or changed gas solubility, must be the real reason for graphite subdivision—regardless of various explanatory hypotheses on the destruction of graphite nuclei. I could actually prove this supposition by the following experiment:

Metal Poured Into a Mold With Variously Heated Sections

Three heats of iron of identical material, and approximating the same composition (Total carbon 3.00; silicon 2.20; manganese 0.45; phosphorus 0.02; with traces of sulphur) were made

in an experimental crucible furnace. The first melt was superheated to 2300 degrees Fahr., the second to 2600 degrees Fahr., and the third up to 2900 degrees Fahr. All melts were allowed to remain at their respective maximum temperatures for 10 minutes and each promptly poured into a test bar 1.20 inches diameter and about 20 inches in length, using the mold arrangement shown in Fig. 4. This mold was specially devised to provide means for obtaining wide ranges of the cooling rate, and consisted of 5 parts of equal height; a chiller section, a green-sand, a dry-sand section and a section heated to 930 degrees Fahr., in the order shown, on top of these the pouring basin dimensioned large enough to serve as a sink-head. The preheating of the mold sections in question was brought about by

Table 6

INFLUENCE OF RATE OF COOLING AND OF SUPERHEATING UPON THE EUTECTIC FREEZING TEMPERATURE (PIWOWARSKY)

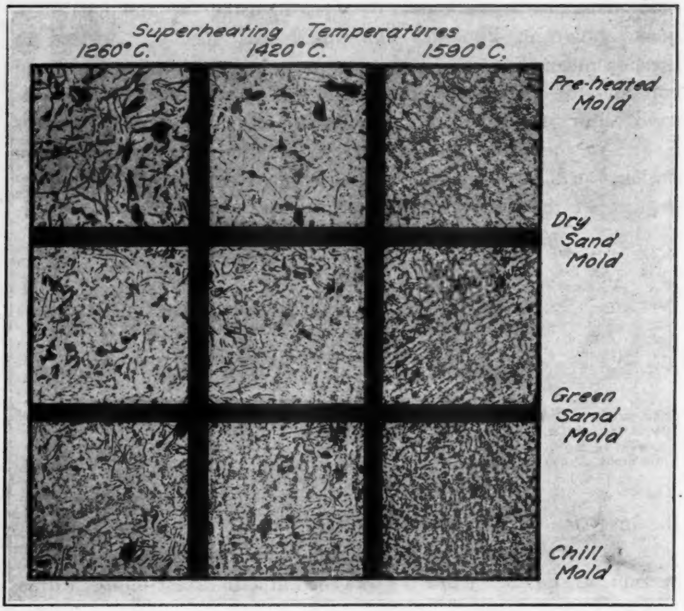
	Pouring Temperatures		
	Heat No. 1 2,300° F.	Heat No. 2 2,600° F.	Heat No. 3 2,900° F.
Kind of Mold	Eutectic Temperatures, Degrees Fahr.		
Sand mold, heated to 932 degrees Fahr.	2,165	2,150	....
Dry sand mold	2,105	2,095	2,065
Green sand mold	2,075	2,060	2,015
Chill mold	....	....	1,855

the insertion of a ni-chrom electric heating coil while ramming up. A thermo couple was inserted in the middle of each mold section, as shown. Table 6 gives the eutectic arrest-temperatures.

Conclusions Drawn from Investigation of Heated Mold Sections

It will be seen from the results obtained that not only the rate of cooling (vertical figures), but also the degree of superheat (horizontal figures) exert an equally directed influence upon the position of the eutectic temperature. In view of the retarded rate of cooling due to increasing pouring temperatures, as shown in the horizontal divisions, one would rather have expected a raising of the eutectic arrest-temperature (in correlation with the rates of cooling shown in the vertical divisions). Yet, beyond the equalization of the effect of this increasing retardation there appeared on higher degrees of superheat, quite contrariwise, a

rapidly increasing retardation of solidification below the freezing (setting) points of the melts. This observation consequently furnishes the explanation, in figures, for the mechanism of the graphite subdivision as the degree of superheat increases.



2,300° F. 2,590° F. 2,900° F.

FIG. 5.—INFLUENCE OF RATE OF COOLING WITH VARYING SUPERHEATING TEMPERATURES OF THE IRON, UPON THE GRAPHITE FORMATION.

Fig. 5 shows the graphite formation of these three heats in the several zones of the best bars, at points taken just below the location of the temperature measurement. It will be noticed from the vertical divisions, that as the rate of cooling is retarded with increasing temperatures of superheat, the increasing coarsening of the graphite crystals is plainly impeded. It follows, therefore, that the molten iron, superheated to the abnormal point of

2900 degrees Fahr., becomes much less sensitive, so far as its graphite formation is concerned, to changes in the rate of cooling, or, what is the same thing, it is less dependent upon the thickness of section, retaining the finely divided graphitic structure more readily even with slow rates of cooling (heavy sections). The ultimate result of this systematic subdivision of the graphite, by reason of abnormal superheating, is a *systematic retardation of solidification below freezing temperatures on the part of the melt without increasing the rate of cooling.* The application of abnormal superheating temperatures has, therefore, accomplished what E. Schuetz[17] obtained with his chill cast iron of about 3.5 per cent total carbon; namely, the formation of graphite in a

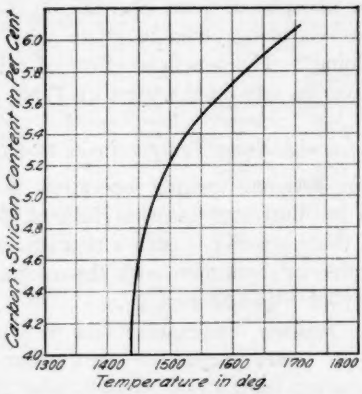


FIG. 6—HEATING CURVE TO OBTAIN EUTECTIC STRUCTURE OF THE GRAPHITE—TEMPERATURES GIVEN IN DEGREES CENT.

finely divided, eutectic state. The method of applying abnormal superheat, therefore, has the advantage of being applicable to all cooling rate conditions, for all irons, irrespective of their composition.

Relation Between Chemical Composition and Superheating

The relations between chemical composition and superheating were recently investigated more thoroughly by means of

[17] Cf. *Stahl und Eisen*, 1925, No. 5, p. 144.

systematic tests made under abnormal superheatings at the Esslingen works in the Wuest oil-fired furnace. The specific minimum temperatures were obtained which must be reached for given silicon and total carbon content of the irons in question, in order that carbon may be precipitated in its eutectic form. (Fig. 6.)

Strengths up to 59,750 pounds per square inch tensile, and a modulus of rupture of 103,825 pounds on bending to destruction, have been attained without subsequent heat treatment (see material of Plant D, in Table 16), by operating under the superheating method in question in the production of high-test cast iron. Strengths up to 51,200 pounds per square inch tensile could be obtained even from the cupola, with irons running about 0.40 per cent of phosphorus (see No. 425, in Table 4), extra precautions, however, being taken to attain very high temperatures when so doing.[18] The beneficial effect of a high degree of superheat may also be seen in the irons of Table 20.

Relation Between Melting Temperatures and Contraction

The relation between melting operation and contraction phenomena will be illustrated in what follows, for, as will be proven later on, there actually is such a relation, and it is of the greatest importance in connection with the internal stresses and volume constancy of high-test cast iron.

Since higher pouring temperatures are used more generally today, there is a better degree of temperature equalization throughout the casting being made possible. As the temperature differences between surface and interior of the casting are lessened, contraction effects are also reduced. This is also in accord with the fundamental conception of "internal shrinkage." It was possible to furnish qualitative proof of the above by pouring off a series of rather large grids.

Further Investigations of Relation Between Superheating and Contraction

The greater degree of contraction while in the fluid state, where higher pouring temperatures are used, and the consequent

[18] Interposition of a fore-hearth omitted.

stronger tendency on the part of such molten metal to feed up well should, however, not be confounded with the above described contraction process occurring during the change in the state of the aggregates. Experimental attempts made at my solicitation to obtain numerical values of the contraction occurring in three series of irons with decreasing silicon content, each of equal temperature, with increasing degrees of superheat—the measurements being made with Wuest's contraction apparatus as improved by Ebbefeld and Bardenheuer—unfortunately did not

Table 7

EXPANSION AT MOMENT OF SET DEPENDING UPON PRECEDING SUPERHEATING, THE POURING TEMPERATURE BEING THE SAME IN EACH CASE

Heat No.	Total Carbon Per Cent	Graphite Per Cent	Silicon Per Cent	Super-heated to Degrees Fahr.	Poured at Degrees Fahr.	Actual Contraction Per Cent	Expansion* Per Cent	Total Contraction
1	3.26	3.02	2.24	2,370	2,280	0.385	0.352	0.737
2	3.30	2.51	2.18	2,640	2,280	0.320	0.529	0.849
3	3.23	1.99	2.24	2,910	2,280	0.753	0.240	0.993
4	3.52	3.08	1.74	2,370	2,280	0.497	0.192	0.689
5	3.36	1.71	1.54	2,640	2,280	0.833	0.448	1.281
6	3.56	2.22	1.74	2,910	2,280	0.432	0.417	0.849
7	3.28	1.51	0.82	2,370	2,280	0.933	0.256	1.189
8	3.02	1.23	0.98	2,640	2,280	1.008	0.481	1.489
9	3.24	1.16	0.92	2,910	2,280	1.300	0.096	1.396

*At moment of set.

result in showing a clear-cut relationship between the true contraction and increasing superheat.[19] Solely the influence of an increasing silicon content upon the diminution of the true contraction could be plainly recognized here. The actual contractions were as follows: (Cf. Table 7).

Series I. Silioon 2.00—Average Contraction 0.486 Per Cent

Series II. Silicon 1.60—Average Contraction 0.587 Per Cent

Series III. Silicon 0.95—Average Contraction 1.08 Per Cent

[19] This can be traced to an insufficiency of accuracy on the part of the method. It were better to carry out suitable tests using the method of Pascal and Pluchs, or still better, that of Bornemann and Sauerwald.

Expansion During Setting

These tests, on the other hand, brought out another correlation, which is at least as important. The *expansion during the moment of set* was always smaller in the case of the lowest and highest degrees of superheating than with the intermediate ones, in which—or directly below their range—there lie the usual normal maximum treatment and pouring temperatures of cast iron in daily practice. One might be tempted to infer from this a preference for the melting and pouring requirements in use at the present time, since the augmented expansion during the

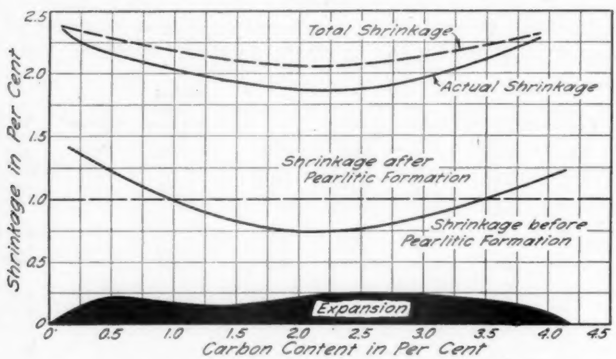


FIG. 7—SHRINKAGE IN RELATION TO CARBON PER CENT

moment of set is able to reduce the amount of true contraction. Were this expansion phenomenon during the moment of set perhaps only the result of a carbide disintegration, I would consider such a conclusion correct. However, we note from the contraction measurements of Wuest[20] and Shitzkowski (Fig. 7) that pure iron-carbon alloys below 1.7 per cent in carbon content —which consequently set without the formation of Ledeburite— also show expansion during the moment of set. I am inclined, therefore, not to discard the views of Ebbefeld and Bardenheuer,[21]

[20] *Mitteilungen aus dem Kaiser Wilhelm Institut fuer Eisenforschung,* Vol. IV, p. 105.

[21] Ibid., Vol. IV (1925), p. 45.

who hold that the separation of the occluded gases during the transition from the fluid to the solid aggregates should be made responsible for the expansion phenomenon described. These two investigators have shown, among other things, that in increasingly rapid melting procedure for cast iron, in a vacuum, the expansion during the moment of set otherwise observable when melting in the atmosphere, can be made to gradually disappear. Ebbefeld and Bardenheuer, however, conducted their researches under melting temperature conditions but little above 2370 degrees

Table 8

QUANTITY AND COMPOSITION OF VARIOUS GASES, WHICH WERE LIBERATED IN THE SETTING OF GRAY IRON RICH IN PHOSPHORUS; IN RELATION TO SUPERHEATING WHILE MOLTEN (PIWOWARSKY AND WÜSTER)

Heat No.	Temperature Degrees Fahr.	Cubic Inches Gas Per Pound Iron	Gas Analysis (Volume Per Cent) CO_2	N_2	H_2	CO	CH_4
1	2,320	1.36	8.22	19.00	63.85	2.85	6.08
2	2,335	2.06	5.51	25.20	39.60	20.42	9.24
3	2,370	1.25	14.90	23.42	36.20	15.33	9.36
4	2,410	1.68	18.12	8.74	18.00	47.00	8.15
5	2,445	1.49	14.30	18.66	31.99	24.18	10.90
6	2,455	1.45	14.78	18.48	42.80	11.08	13.02
7	2,460	1.22	20.31	10.62	33.31	27.28	8.48
8	2,500	1.44	12.33	15.30	31.60	29.90	10.88
9	2,535	2.36	13.12	15.75	29.67	29.67	11.81
10	2,550	1.55	19.25	15.40	25.63	31.53	8.20
11	2,570	2.39	7.62	12.57	32.98	24.00	22.83
12	2,615	2.74	15.90	7.94	40.50	26.20	9.54
13	2,625	2.53	18.06	15.30	27.80	32.32	6.39
13a	2,625	2.14	12.50	13.40	32.34	29.28	12.50
14	2,730	1.31	16.09	9.70	38.72	27.20	8.25
15	2,770	2.70	9.36	20.43	36.81	26.61	6.73
16	2,860	1.81	17.70	13.80	33.60	23.05	11.91
17	2,910	1.47	14.70	13.10	34.60	30.40	7.08
18	2,910	1.12	12.11	8.46	41.10	32.10	6.20

Fahr. The expansion during the moment of set, as I observed it, would seem to justify the conclusion that as the temperatures increase above a given critical range, the evolution of gases in cast iron during the moment of set decreases again. This interpretation seems to be verified by results from tests made with newly devised apparatus—though the tests are unfortunately still uncompleted.[22] Table 8 gives the volume of gases obtained during the setting of high phosphorus irons under increasing temperatures of superheat. Even if these figures are not fully conclusive,

[22] To be described, shortly, in *Stahl und Eisen*.

the tendency of the inverted curve with a maximum of evolved gases in the medium temperature ranges is very evident. (See the graphic representation of the data in Fig. 8.)

Former Theories May Be Erroneous

Should these observations be further substantiated, the above discussed expansion during the moment of set would prove to be not only of little use, but actually harmful; for the extent of this expansion could then be taken as a measure of the decrease in density consequent to the evolved gases causing porosity in

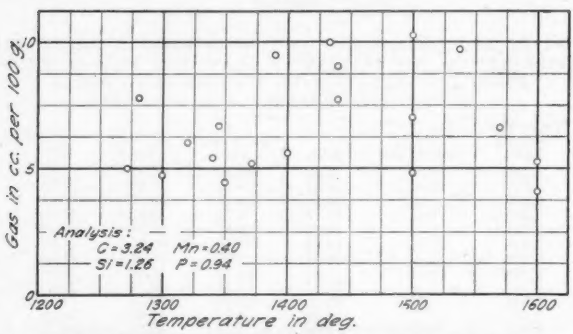


FIG. 8—INFLUENCE OF TEMPERATURE OF THE MELTED IRON UPON THE QUANTITY OF GAS ESCAPING DURING THE SOLIDIFICATION OF GRAY CAST IRON. THE TEMPERATURES ON THE DIAGRAM ARE GIVEN IN DEGREES CENT. AND CORRESPOND (READING FROM LEFT TO RIGHT) TO 2,190, 2,370, 2,550, 2,730 AND 2,910 DEGREES FAHR.

the material. As a matter of fact, some very careful determinations of density conducted later have verified this assumption. (See values for specific gravity in Table 14.)

Greater Density of Highly Superheated Iron Produces Favorable Effect

For a long time I have vainly sought for an explanation of my numerous observations to the effect that only a very high degree of superheat—not current in practice heretofore—produces an optimum of physical properties in cast iron; even though medium high ranges of superheat already produce a marked

increase in fineness on the part of the graphite. I take it, therefore, *that the greater density of abnormally superheated cast iron, in conjunction with the distribution of fine graphite, explains the markedly beneficial effect of this melting procedure.* This would also partially explain my observation that to obtain the optimum of physical properties, the degree of required superheat will change with the chemical composition. For instance, as the silicon content rises the degree of superheat given the metal may be lowered.[23] Silicon in iron, namely, lessens the possibility of coexistence of an easily reduced and gas producing ferrous oxide. It also lessens the solubility of hydrogen in iron, as indicated by Troost and Hautefeuille in 1876. In fact, Ebbefeld and Bardenheuer found a diminution in expansion at the moment of set, in their tests, when the silicon increased, as shown in Table 9. All of which would bring us to the following conception of the occurrences in question:

Table 9

INFLUENCE OF PERCENTAGE OF SILICON UPON CONTRACTION (ACCORDING TO EBBEFELD AND BARDENHEUER)

Heat No.	Total Carbon Per Cent	Graphite Per Cent	Silicon Per Cent	Total Contraction Per Cent	Expansion* Per Cent	Pouring Temperature Degrees Fahr.
69	3.40	2.15	1.26	1.341	0.169	2,380
86	3.25	2.30	2.00	1.220	0.057	2,250
85	3.23	2.44	3.24	1.163	0.054	2,215
87	3.15	2.44	3.56	1.011	0.024	2,250

*At the moment of set.

Conclusions Drawn from Superheating Experiment

1. The increasing carbide formation in cast iron when set *always* seen with increasing degrees of superheat given the metal when molten, would be explained by the disappearance of mechanically disseminated graphite particles, as well as an increase in the carbide molecules in the melt. (Koerber, Hanemann, Sauerwald.)

2. The diminution in size of the graphite particles already becoming more apparent as the medium ranges of superheat are reached, is brought about through the gradual decrease of the

[23] Cf. *Stahl und Eisen*, 1925, p. 1455.

critical eutectic temperature, since setting takes place increasingly in the regions of spontaneous crystallization. The disappearance of the graphite nuclei* *overbalances* in its influence the opposing tendency of the gases—in variable volume in the setting iron—to promote solidification below normal freezing temperatures together with an increased disintegration of carbide. Also (in case of pouring off hotter) the influence of a retardation in the rate of setting results from a more effective preheating of the mold by reason of the increased pouring temperature.

3. The increasing rate of subdivision of the graphite particles observed when superheating to a higher degree could then be attributed to the increasing tendency toward setting at temperature ranges considerably below normal freezing, and increasingly growing spontaneous crystallization—as a consequence of the gradual diminution of evolved gases from the melt. The proportion of graphite increase in the solid phase to the total carbon content (critical temperatures, inverse curves) might be explained as in

(a) By the faster and stronger development of sensible heat at increasing setting tendencies below normal freezing points; and the annealing effect of this upon the carbide.

(b) By the increasing formation of molecules of the elementary carbon arrangement in the melt (dissociation) on passing the critical temperature.

(c) In the case of pouring off at these higher temperatures into intensively preheated molds, by the *only now* fully effective retardation of the rate of cooling within or just below the point of set.

Jolting of the Molten Iron

The beneficial effect of the graphite subdivision and reduced gas evolution upon the quality of cast iron when subjected to abnormally high temperatures could also be expected, from the foregoing discussion, had the molten metal been treated while under a vacuum at somewhat lower temperatures (2550 to 2730 degrees Fahr.); or had it been "jolted" with suitable mechanical contrivances. K. Irresberger[24] was able to obtain very good

*Confer footnote on page 920.

[24] Cf. *Giesserei-Zeitung*, 1926, p. 355.

physical properties when jolting his molten cupola metal in a forehearth equipped with a motor-operated eccentric lifting and dropping base. The figures are given in Table 10. In order to effect the removal of gases and slag still better, the author[25] has proposed that the forehearth or mixing-ladle be given a rotating motion, so that the lighter non-metallic inclusions may be forced inward by centrifugal action and thus be given opportunity to rise and enter the slag.

Theories Based on Formation of Graphite Above Critical Temperature

So far as the increasing tendency on the part of the iron to precipitate graphite in passing the critical temperature is concerned, an increased tendency toward graphitization, as compared with the medium ranges of superheat, must be deduced even where the graphite percentages of the abnormally heated metal remain constant. This, because the influence of the evolved gases favoring the disintegration of carbide (Maurer, Honda and Murakami) during the moment of set, is gradually diminished and must be compensated. Attention has been called from various sources to the fact that my conception of the coexistence of two varieties of molecules in the molten iron—each variety in balance with its products of dissociation—is based upon too few observed facts[26], or may even be based upon erroneous data.[27] It was pointed out[28] that if I were correct in my assumptions, that Sauerwald should also have found an inversion of the specific volume when making his density determinations[29] of molten iron. These claims do not seem to me to be fully justified—for the specific volumes of white and gray pig irons do not vary from each other more than one per cent, according to the results obtained by F. Sauerwald and J. Wecker. (From this there can incidentally be deduced that the greater part of carbon in gray iron is dissolved in it in carbide form, for a transformation of but 0.6 per cent combined carbon, equaling 9 per cent Fe_3C, into

[25] German patent applied for.
[26] The Superheating of Cast Iron, *The Metallurgist*, Jan. 29, 1926.
[27] Correspondence between Kerpely and Wedemeyer, *Stahl und Eisen*, 1926, p. 874.
[28] Cf. footnote 3.
[29] *Zeitschrift fuer Anorganische Chemie*, 1925, Vol. 149, p. 273.

Table 10

STRENGTH FIGURES OF IRON JOLTED IN FOREHEARTH (ACCORDING TO K. IRRESBERGER)

No.	Per Cent Steel in Mixture	Carbon	Silicon	Manganese	Phosphorus	Sulphur	Tensile Strength, Pounds Per Square Inch	Bending Strength, Pounds Per Square Inch	Deflection in Inches	Brinell Hardness	Forehearth End Temperature Degrees Fahr.
1	0	3.72	2.22	0.46	0.37	0.17	29,160	59,735	0.443	222	2,410
2	10	3.20	2.27	0.56	0.38	0.08	36,980	72,535	0.492	216	2,390
3	15	3.40	2.34	0.45	0.33	0.09	39,115	74,670	0.492	228	2,370
4	20	3.38	2.15	0.42	0.37	0.13	42,670	80,360	0.492	217	2,425
5	20	3.62	1.74	0.71	0.30	0.17	43,383	77,660	0.560	240	2,370
6	30	3.48	2.15	0.45	0.20	0.13	46,225	78,940	0.551	215	2,480
7	30	3.48	1.57	0.68	0.41	0.14	48,070	81,780	0.469	224	2,545
8	50	3.02	1.83	0.40	0.34	0.14	47,650	87,470	0.492	215	2,545
9	70	2.82	2.94	0.66	0.15	0.14	46,225	92,450	0.709	189	2,460

Table 11

SUMMARY OF TEST CONDITIONS AND RESULTS OF WEDEMEYER

Heat No.	Test No.	Tons	Material	Heat Begun, P. M.	Sample Taken, A. M.	Temp. Bath, Degrees Fahr.	Total Time Heat, Hours	Time Super-heat, Hours	Total C.	Comb. C.	Graph.	Si.	Mn.	P.	S.
1	13	28.6	Chilled Rolls	5:30	7:05	.....	.....	....	2.94	0.82	2.12	0.59	1.08	0.31	0.086
1	14	28.6	Chilled Rolls	....	8:00	.....	.....	....	2.94	0.96	1.98	0.56	....	....	....
1	15	28.6	Chilled Rolls	....	8:55	.....	.....	....	2.94	1.00	1.94	0.56	....	....	....
1	16	28.6	Chilled Rolls	....	10:00	2,320	16:45	3:00	2.90	1.18	1.72	0.59	1.07	0.31	0.090
2	17	18.7	Chilled Rolls	6:00	6:05	2,460	.....	....	2.86	1.14	1.72	0.54	1.12	0.30	0.078
2	18	18.7	Chilled Rolls	....	7:10	.....	.....	....	2.81	1.40	1.41	0.52	....	....	....
2	19	18.7	Chilled Rolls	....	8:40	2,500	.....	....	2.84	1.79	1.05	0.51	....	....	....
2	20	18.7	Chilled Rolls	6:00	9:20	.....	15:30	3:15	2.82	1.86	0.96	0.50	1.12	0.30	0.073
3	21	23.1	Chilled Rolls	7:00	6:00	2,320	.....	....	2.88	0.66	2.22	0.66	0.89	0.28	0.090
3	22	23.1	Chilled Rolls	....	7:10	.....	.....	....	2.89	0.72	2.17	0.65	....	....	....
3	23	23.1	Chilled Rolls	....	8:10	2,365	.....	....	2.89	0.92	1.97	0.65	....	....	....
3	24	23.1	Chilled Rolls	7:00	9:30	.....	14:45	3:30	2.84	0.95	1.89	0.61	0.93	0.27	0.097
4	25	15.4	Chilled Rolls	6:00	6:40	.....	.....	....	2.82	1.12	1.70	0.46	0.83	0.32	0.085
4	26	15.4	Chilled Rolls	....	7:45	.....	.....	....	2.77	2.43	0.34	0.35	....	....	....
4	27	15.4	Chilled Rolls	....	8:55	.....	.....	....	2.78	2.61	0.17	0.33	....	....	....
4	28	15.4	Chilled Rolls	....	9:50	2,365	16:00	3:15	2.77	2.57	0.20	0.32	0.81	0.29	0.086
5	30	19.8	Chilled Rolls	8:30	7:30	.....	.....	....	2.77	0.80	1.97	0.50	0.93	0.32	0.078
5	31	19.8	Chilled Rolls	....	8:15	.....	.....	....	2.79	1.49	1.30	0.48	....	....	....
5	32	19.8	Chilled Rolls	....	9:00	.....	.....	....	2.82	2.18	0.64	0.46	....	....	....
5	33	19.8	Chilled Rolls	....	10:05	2,280	14:00	3:00	2.84	2.53	0.31	0.45	0.92	0.32	0.078

(Concluded on next page)

Table 11—(Concluded)

Heat No.	Test No.	Tons	Material	Heat Begun, P. M.	Sample Taken, A. M.	Temp. Bath, Degrees Fahr.	Total Time Heat, Hours	Time Super-heat, Hours	Total C	Comb. C.	Graph.	Si.	Mn.	P.	S.
6	49	23.1	Chilled Rolls	6:00	6:45	.....	.....	....	2.97	0.83	2.14	0.48	0.83	0.31	0.083
6	50	23.1	Chilled Rolls	....	7:25	.....	.....	....	2.91	1.01	1.90	0.47	....	....	....
6	51	23.1	Chilled Rolls	....	8:00	.....	.....	....	2.90	1.05	1.85	0.46	....	....	....
6	52	23.1	Chilled Rolls	....	8:50	.....	.....	....	2.86	1.61	1.25	0.45	....	....	....
6	53	23.1	Chilled Rolls	....	9:25	2,405	16:00	3:00	2.80	1.98	0.82	0.43	0.85	0.31	0.083
7	34	19.25	Chilled Rolls	8:00	6:45	.....	.....	....	2.66	2.28	0.38	0.41	0.86	0.318	0.108
7	35	19.25	Chilled Rolls	....	7:20	.....	.....	....	2.69	2.41	0.28	0.41	....	....	....
7	38	19.25	Chilled Rolls	....	9:10	2,335	14:00	3:30	2.69	2.51	0.18	0.38	0.84	0.315	0.110
8	54	27.5	Machinery*	4:00	7:30	.....	.....	....	3.57	0.81	2.76	1.24	0.56	0.114	0.057
8	56	27.5	Machinery*	....	8:30	.....	.....	....	3.54	0.82	2.72	1.23	....	....	....
8	58	27.5	Machinery*	....	9:30	.....	.....	....	3.63	0.97	2.66	1.23	....	....	....
8	60	27 5	Machinery*	....	10:15	2,355	18:30	3:00	3.66	1.00	2.66	1.23	0.59	0.114	0.060
9	61	12.1	Machinery*	10:00	6:10	.....	.....	....	3.83	0.89	2.94	1.72	0.74	0.093	0.046
9	64	12.1	Machinery*	....	7:55	.....	.....	....	3.68	0.83	2.85	1.65	....	....	....
9	66	12.1	Machinery*	....	8:50	.....	.....	....	3.76	0.96	2.80	1.64	....	....	....
9	67	12.1	Machinery*	....	9:00	2,340	11:30	3:30	3.68	1.03	2.65	1.62	0.74	0.092	0.046

*Hematite pig.

elementary carbon and iron is already coexistent with a dilation of one per cent. If, now, the mass of molecules available for this transformation is smaller than would correspond to 0.6 per cent carbon, the molecular transformation will not be noticeable when measured by apparatus sensitive to changes of plus and minus one per cent. In the meantime, however, Wedemeyer[30] (see Table 11) conducting tests in a coal-fired air furnace on a factory scale, had found my observations to be correct. His tests, however, did not extend beyond the critical temperature region.

Carbide Content Dependent Upon Degree and Duration of Superheat

Wedemeyer found that the carbide content of castings was dependent in the same sense upon the height reached by the temperature of superheating as well as its duration, as I had announced it in my first publication.[31] He also verified the decreasing quantitative controlling ability as the silicon content rose, for, in making rolls with 0.45 to 0.60 per silicon, the differences in carbide content came out greater by reason of the conduct of the melting process than where hematite ore pig iron of 1.25 to 1.75 per silicon had been used. F. Meyer,[32] in his recent voluminous tests, also found my observations generally verified.

F. Meyer undertook to set up four groups of test series, which differed from each other in the type of furnace used, the mixture taken, the quantity involved and the material of the crucible itself. He made use of both high and low total carbon alloys and high grade, pure pig irons. Fig. 9 explains his melting program. The analyses of the individual heats and the dependence of the forms of the carbon upon the degrees of superheat are given in Tables 12 and 12a, as also graphically in Fig. 10. To be more independent of the disturbing influence of silicon and carbon losses in melting, F. Meyer selected the percentual

[30] *Stahl und Eisen,* 1926, p. 557.
[31] *Stahl und Eisen,* 1925, p. 1455.
[32] Dissertation, Aachen, 1926, to appear in *Stahl und Eisen* in the near future.

FIG. 9—PROGRAM OF MELTING AND EXPERIMENTS OF F. MEYER

Group No.	Type of Furnace	Mix	Weight of Heats i. g.	Type of Crucible	Original Alloy Melted In	Minutes Held at Maximum Temp.	Heated to 1250 °C
Ia	Fletscher Crucible Furnace Closed Hearth	High Carbon	80.000	Graphite Lined with Magnesite and Clay	Cupola		Poured into Dry Sand Molds
Ib	"	Low Carbon	8.000	"	"		"
II	Borchers Cupola	Series 7 Low Carbon Series 8 High Carbon	125	"	"	5	Removed from Furnace and Air Cooled
III	Tammaun Electric Furnace	High Carbon	150	Alaska Pot	Gas Crucible Furnace	5	Poured into Dry Sand Molds
IV	"	Pig Iron	250	D4 and Alaska Pot	Blast Furnace	5	Cooled in Kieselgur (infusorial earth)

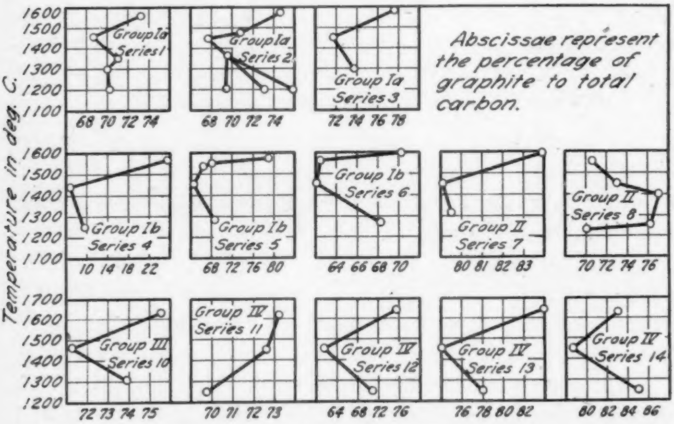


FIG. 10—INFLUENCE OF SUPERHEATING TEMPERATURE UPON GRAPHITE FORMATION IN SOLIDIFIED GRAY CAST IRON (ACCORDING TO CONTROL EXPERIMENTS BY F. MEYERS)

Table 12

EFFECT OF HEATING TO VARYING TEMPERATURES AND POURING INTO DRY SAND MOLDS AT 2,280 DEGREES FAHR.*

Group No.	Test Series	Melt No.	Heated to Deg. Fahr.	T. C.	C. C.	G. C.	Si.	Mn.	P.	S.	G. C. & T. C.**
Ia	1	1	2,280	3.78	2.65	0.89	0.77	0.23	0.23	0.062	0.702
Ia	1	2	2,370	3.76	1.13	2.63	0.70	0.25	0.25	0.119	0.700
Ia	1	3	2,460	3.58	1.04	2.54	0.61	0.76	0.26	0.114	0.710
Ia	1	4	2,640	3.63	1.13	2.50	0.86	0.81	0.23	0.085	0.688
Ia	1	5	2,785	3.45	0.92	2.53	0.65	0.66	0.24	0.106	0.733
Ia	2	9	2,280	3.38	0.83	2.55	1.32	0.72	0.22	0.079	0.754
Ia	2	10	2,280	3.62	0.97	2.65	1.39	0.81	0.22	0.080	0.732
Ia	2	11	2,280	3.63	1.10	2.53	1.45	0.76	0.20	0.079	0.697
Ia	2	12	2,515	3.52	1.06	2.46	1.63	0.75	0.22	0.076	0.699
Ia	2	13	2,625	3.61	1.19	2.42	1.48	0.76	0.24	0.072	0.671
Ia	2	14	2,625	3.45	1.11	2.34	1.87	0.75	0.23	0.078	0.678
Ia	2	15	2,640	3.26	0.95	2.31	1.97	0.70	0.21	0.094	0.709
Ia	2	16	2,860	3.44	0.88	2.56	1.29	0.80	0.22	0.081	0.743
Ia	3	22	2,370	3.57	0.93	2.64	3.37	0.71	0.20	0.07	0.739
Ia	3	23	2,640	3.25	0.93	2.32	3.65	0.78	0.22	0.07	0.714
Ia	3	24	2,875	3.50	0.78	2.72	3.27	0.80	0.21	0.073	0.778
Ib	4	26	2,280	2.89	2.67	0.38	0.85	0.84	0.10	0.181	0.131
Ib	4	27	2,640	2.78	2.67	0.29	0.90	0.83	0.11	0.160	0.104
Ib	4	28	2,840	3.00	2.17	0.83	0.86	0.79	0.092	0.148	0.277
Ib	5	30	2,320	2.97	0.95	2.02	1.86	0.80	0.11	0.132	0.682
Ib	5	31	2,550	3.02	1.00	2.02	1.86	0.81	.....	.....	0.668
Ib	5	32	2,550	3.14	1.10	2.04	1.40	0.84	0.099	0.134	0.650
Ib	5	33	2,805	2.79	0.93	1.86	1.47	0.87	0.097	0.143	0.667
Ib	5	34	2,840	2.76	0.89	1.87	1.62	0.78	0.11	0.142	0.678
Ib	5	35	2,860	2.48	0.47	2.01	1.59	0.85	0.097	0.158	0.810
Ib	6	38	2,320	2.96	0.94	2.02	1.86	0.80	0.11	0.132	0.682
Ib	6	39	2,660	2.92	1.11	1.81	2.11	0.88	0.11	0.155	0.620
Ib	6	40	2,840	3.01	1.14	1.87	1.91	0.98	0.099	0.153	0.622
Ib	6	41	2,910	2.50	0.74	1.76	1.73	0.55	.....	.....	0.704

*Groups Ia and Ib poured at 2,280 degrees Fahr. into dry sand molds.
**Graphite and total carbon index.

Table 12a

Group No.	Test Series	Melt No.	Heated to Deg. Fahr.	Analyses in Per Cents: T. C.	C. C.	G. C.	Si.	Mn.	P.	S.	G. C. & T. C.**
II	7	44	2,390	3.17	0.65	2.52	3.55	0.83	0.23	0.088	0.795
II	7	45	2,640	3.09	0.64	2.45	3.21	0.85	.....	.....	0.792
II	7	46	2,910	2.98	0.47	2.51	4.07	0.70	.....	.....	0.842
II	8	51	2,235	3.32	1.00	2.32	2.04	0.80	0.23	0.082	0.700
II	8	52	2,280	3.37	0.81	2.56	1.77	0.79	.....	.....	0.760
II	8	53	2,550	3.32	0.76	2.56	2.03	0.82	.....	.....	0.770
II	8	54	2,640	3.43	0.93	2.50	1.84	0.81	0.23	0.093	0.728
II	8	55	2,820	3.34	0.98	2.36	2.06	0.88	0.24	0.100	0.706
III	9	56	2,280	3.59	0.70	2.89	1.23	0.59	0.028	0.009	0.805
III	9	57	2,640	3.82	0.28	3.10	1.20	0.60	0.026	0.006	0.812
III	9	58	2,680	3.51	0.57	2.94	1.39	0.60	0.031	0.007	0.838
III	9	59	3,090	2.97	0.72	2.25	1.27	0.59	0.031	0.005	0.758
IV	10	63	2,370	3.57	0.93	2.64	3.16	0.62	0.087	0.025	0.740
IV	10	64	2,640	3.59	1.03	2.56	3.37	0.71	0.084	0.050	0.712
IV	10	65	2,965	3.26	0.80	2.46	3.55	0.70	.....	.....	0.755
IV	11	66	2,280	3.18	0.94	2.25	1.57	0.96	0.067	0.068	0.705
IV	11	67	2,640	3.05	0.85	2.20	2.26	1.01	0.055	0.053	0.722
IV	11	68	2,950	3.10	0.84	2.26	2.18	1.01	.....	.....	0.729
IV	12	69	2,280	2.96	1.16	2.80	0.39	0.35	0.025	0.032	0.707
IV	12	70	2,640	3.61	1.39	2.22	0.45	0.21	.....	.....	0.615
IV	12	71	2,965	3.52	0.93	2.59	0.54	0.31	.....	.....	0.736
IV	13	72	2,280	3.45	0.76	2.69	1.83	0.63	0.060	0.066	0.780
IV	13	73	2,640	3.34	0.87	2.47	1.68	0.61	.....	.....	0.740
IV	13	74	2,980	4.04	0.60	3.44	2.22	0.66	.....	.....	0.852
IV	14	75	2,280	3.46	0.52	2.94	1.77	0.74	0.060	0.044	0.850
IV	14	76	2,640	3.84	0.82	3.02	1.75	0.77	.....	.....	0.787
IV	14	77	2,925	3.54	0.57	2.97	1.74	0.79	.....	.....	0.830

Group II removed from furnace at 2,280 degrees Fahr. and air cooled.
Group III removed from furnace at 2,280 degrees Fahr. and cooled in infusorial earth.
Group IV poured at 2,280 degrees Fahr. into dry sand molds.
**Graphite and total carbon index.

relation of graphite to total carbon as his criterion of the metallurgical reaction of the various degrees of superheat. The tests in Group IV were carried out in an atmosphere of nitrogen. The initial arrangement of irons in this group was as follows:

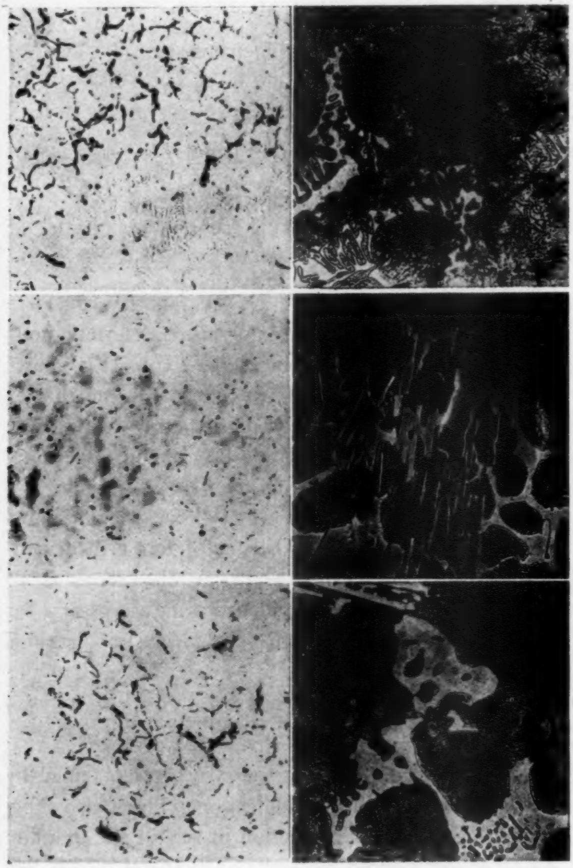
Series 10—French hematite ore pig irons
Series 11—German hematite ore pig irons
Series 12—Swedish charcoal pig irons
Series 14—German hematite ore pig irons

Series 13— {⅓ French hematite ore pig irons, ⅓ German hematite ore pig irons, ⅓ Swedish charcoal pig irons}

Disregarding series 9, which F. Meyer himself considers unreliable on account of inaccurate temperature determinations and excessive carbon reductions and increases (Table 12a shows heat 57 to be over, and 59 to be under eutectic); we find that of the remaining 13 series carried through with the greatest variety of test conditions, only two (series 11 and 8) are contrary to my observations, whereas 11 uphold them. That is, they indicate a critical point of carbide transformation at 2640 degrees Fahr. Aside from its scientific value, the existence of this critical temperature has also a practical value, as it can also serve as an indication of the optimum region of superheating necessary for quality improvement in the cast of cast irons of various composition.

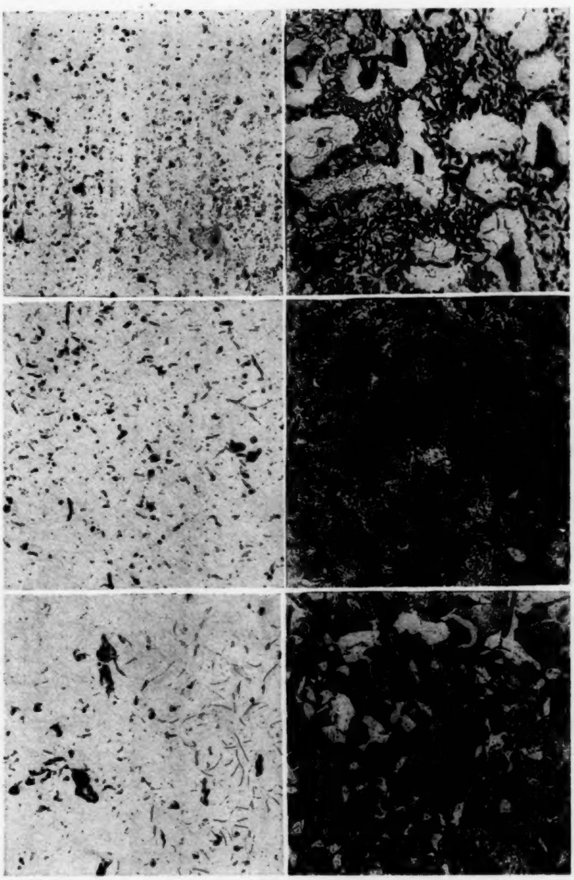
Experiments of F. Meyer

Figs. 11 to 17 illustrate some of the structures obtained by F. Meyer—as reproduced from his publication. These also show the effect of superheating in the reduction in size of the graphite particles. As F. Meyer poured his melts at temperatures as low as 2280 degrees Fahr., in order to exclude the influence of serious variations in pouring temperature, the influence of superheating upon the physical properties of the irons made hardly became discernible. Still, the tendencies anticipated are indicated by the



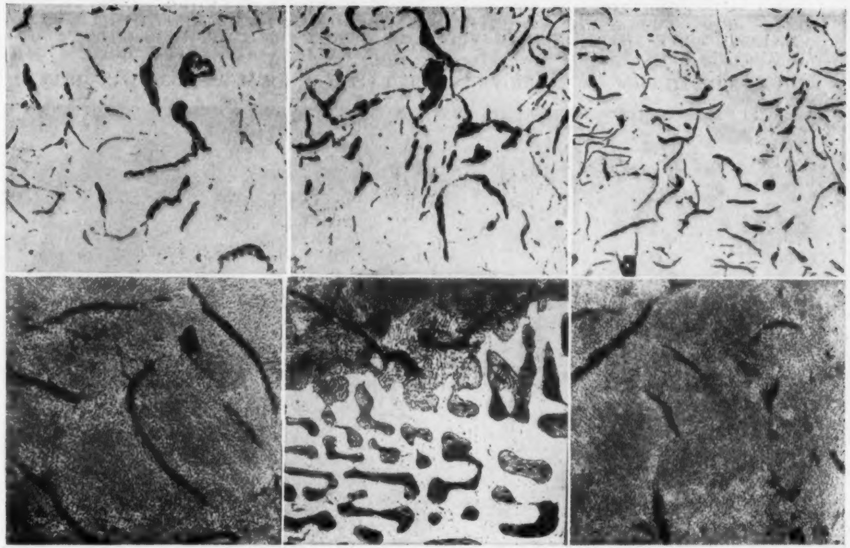
HEATED 2,280 DEGREES FAHR. 2,640 DEGREES FAHR. 2,840 DEGREES FAHR.

FIG. 11—SERIES 4 OF THE EXPERIMENTS OF F. MEYER. UPPER MICROGRAPHS MAGNIFIED 100 DIAMETERS AND NOT ETCHED. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. SPECIMENS WERE POURED IN A DRY MOLD AT 2,280 DEGREES FAHR.



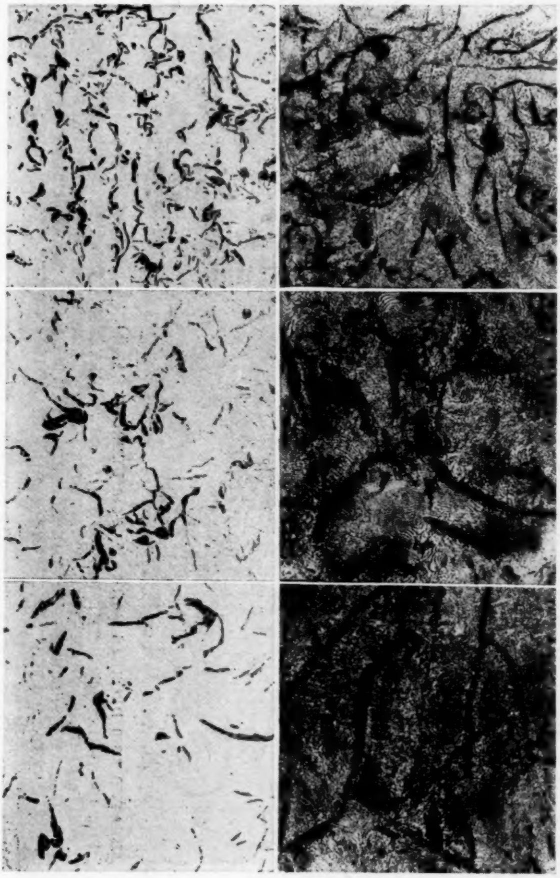
HEATED 2,390 DEGREES FAHR. 2,640 DEGREES FAHR. 2,910 DEGREES FAHR.

FIG. 12—SERIES 7 OF THE EXPERIMENTS OF F. MEYERS. UPPER MICROGRAPHS MAGNIFIED 100 DIAMETERS. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. ALL SPECIMENS WERE SUBJECTED TO AIR COOLING FROM 2,280 DEGREES FAHR.



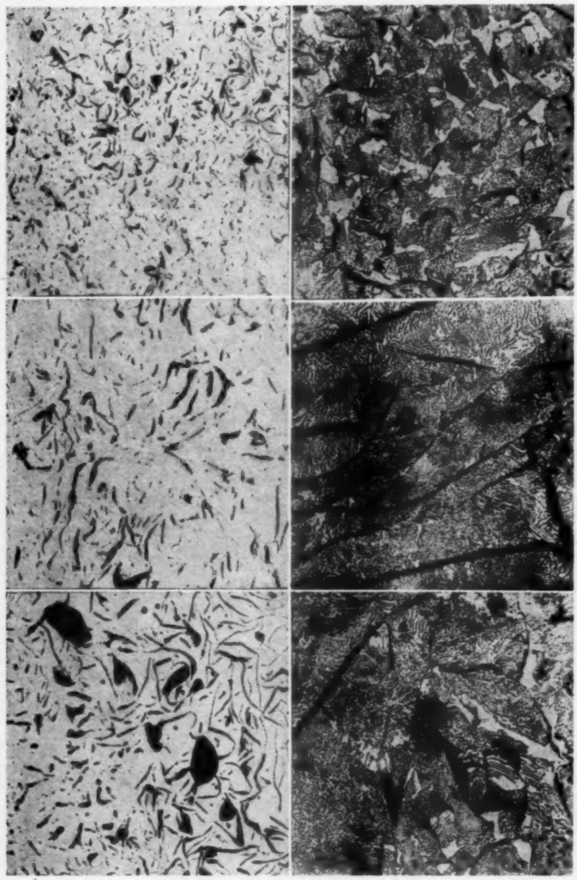
HEATED 2,370 DEGREES FAHR.   2,640 DEGREES FAHR.   2,965 DEGREES FAHR.

FIG. 13—SERIES 12 OF THE EXPERIMENTS OF F. MEYERS — UPPERMICROGRAPHS MAGNIFIED 100 DIAMETERS AND NOT ETCHED. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. ALL SPECIMENS WERE COOLED FROM 2,280 DEGREES FAHR. IN DIATOMACIOUS EARTH (KIESEL-GUHR)



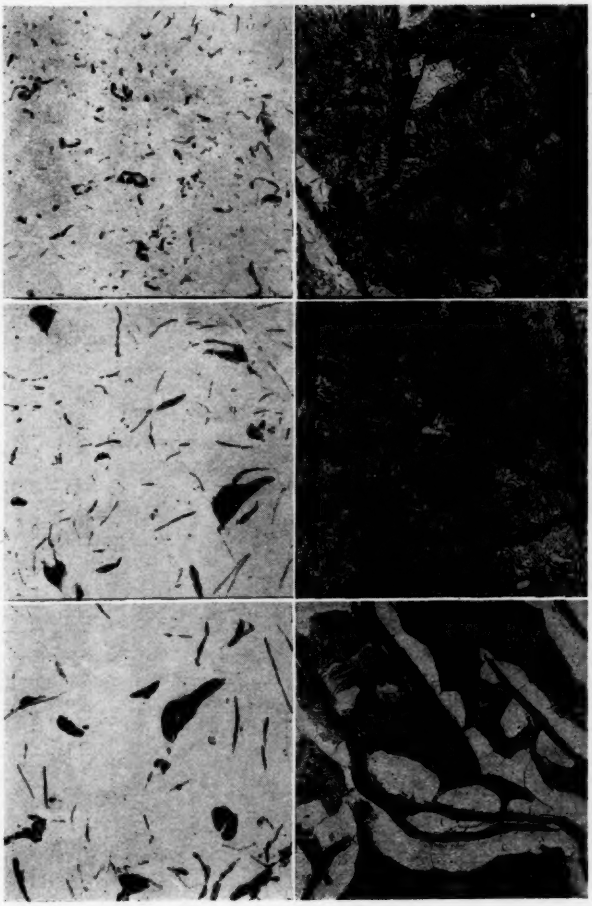
HEATED 2,280 DEGREES FAHR. 2,640 DEGREES FAHR. 2,950 DEGREES FAHR.

FIG. 14—SERIES 11 OF THE EXPERIMENTS OF F. MEYERS—UPPER MICROGRAPHS MAGNIFIED 100 DIAMETERS AND NOT ETCHED. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. ALL SPECIMENS COOLED FROM 2,280 DEGREES FAHR. IN KIESEL-GUHR



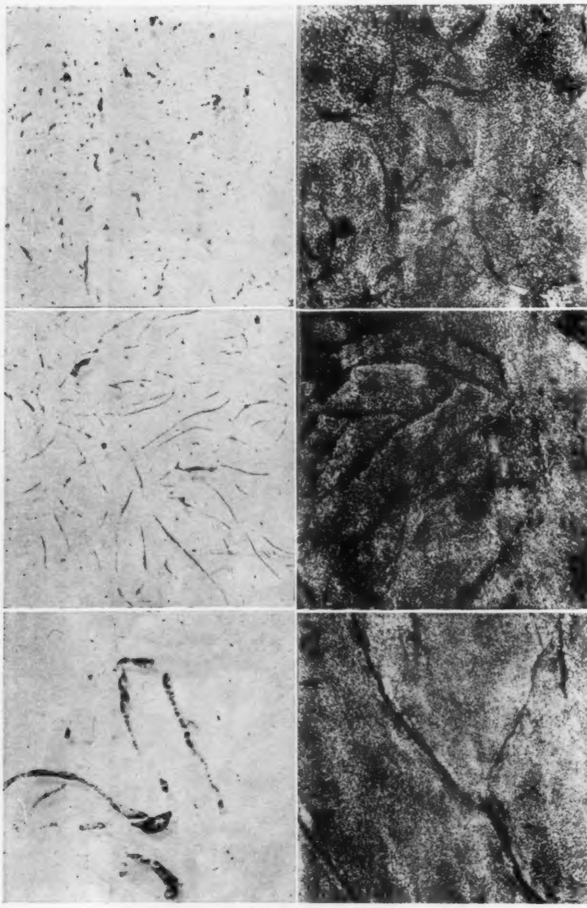
HEATED 2,280 DEGREES FAHR. 2,640 DEGREES FAHR. 2,965 DEGREES FAHR.

FIG. 15—SERIES 10 OF THE EXPERIMENTS OF F. MEYERS. UPPER MICROGRAPHS MAGNIFIED 100 DIAMETERS AND NOT ETCHED. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. COOLED FROM 2,280 DEGREES FAHR. IN KIESEL-GUHR



HEATED 2,280 DEGREES FAHR. 2,640 DEGREES FAHR. 2,985 DEGREES FAHR.

FIG. 16—SERIES 13 OF THE EXPERIMENTS OF F. MEYERS. UPPER MICROGRAPHS MAGNIFIED 100 DIAMETERS AND NOT ETCHED. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. COOLED FROM 2,280 DEGREES FAHR. IN KIESEL-GUHR



HEATED 2,280 DEGREES FAHR. 2,640 DEGREES FAHR. 2,925 DEGREES FAHR.

FIG. 17—SERIES 14 OF THE EXPERIMENTS OF F. MEYERS. UPPER MICROGRAPHS MAGNIFIED 100 DIAMETERS AND NOT ETCHED. LOWER MICROGRAPHS ARE OF THE SAME SPECIMENS AS THE UPPER BUT ETCHED AND MAGNIFIED 400 DIAMETERS. COOLED FROM 2,280 DEGREES FAHR. IN KIESEL-GUHR

figures of Table 13. The existence of a critical temperature was emphasized metallographically in the 4th and 5th series of the investigations of F. Meyer by the appearance of ferrite side by side with pearlite in the melts having the lowest and highest degrees of superheat, whereas the middle ranges, as more likely to lean toward carbide formation, show only pearlite as the matrix (cf. Figs. 12, 15 and 16). In two cases the highest degree of superheat showed pearlite, while the middle range showed pearlite and ledeburite (cf. Figs. 11 and 13).

Table 13

STRENGTH FIGURES OF THE HEATS OF SERIES 1 OF EXPERIMENTS GROUP 1A OF F. MEYERS

Melt No.	Heated to Degrees Fahr.	Poured at Degrees Fahr.	Bending Strength, Pounds Per Square Inch	Bending in Inches in Length 20 x d	Tensile Strength, Pounds Per Square Inch
1	2,280	2,280	43,095	0.441	34,280
2	2,370	2,280	58,455	0.362	33,850
3	2,460	2,280	42,810	0.169	24,320
4	2,640	2,280	59,595	0.441	34,135
5	2,785	2,280	61,585	0.323	41,100

Hypothetical Explanation

Furthermore, I have based my hypothetical explanation of the phenomena in question upon the following reaction:

$$C + 3Fe = Fe_3C + W. E.$$

(W. E. is positive above the critical temperature; W. E. is negative below the critical temperature; W. E. is ± 0 at the critical temperature.) This hypothetical explanation I hold now —but only until it may have become possible to obtain a direct proof of what actually goes on. Besides determining the specific volumes, it may become necessary to obtain the viscosity (complicated molecular formations would be accompanied by high degrees of viscosity—for instance, in the case of a carbide as against an elementary arrangement), also to get the electrical conductivity. I even consider, at this time, that Koerber's[33] theory, holding the superimposition of two diametrically opposed processes—namely, the increasing solution of mechanically mixed graphite particles and the increasing dissociation of molecular iron carbide—to be active

[33] Report of Discussion, *Stahl und Eisen,* 1915, p. 1455.

in promoting inverted curves; is not so unjustified. Furthermore, the gas phase is evidently also quite effective, for when I conducted melts in vacuum the carbide reversal rarely occurred. At any rate Haneman[84] has again been able to verify—as the result of his microscopical examination—that for moderate ranges of superheat, the crystallization brought about by nuclei of undissolved carbon has a potent effect upon the size of the graphite particles, in consequence of the retardation of the setting process in considerably extended regions below the normal freezing point. From my numerous observations and investigations I have concluded that the use of gray-fractured pig iron in the foundry industry retards the complete solution of the graphite when melting under conditions of moderate ranges of superheat.

Process for Producing High-Test Cast Iron

I have, therefore, proposed a simple method for producing high-test cast iron, in which all pig irons—even those with high silicon content—are specified to the furnaces on purchase, to be machine cast; and, if possible, to be water-chilled in addition, irrespective of what they contain. If the melting process in cupola, air furnace or electric furnace is carried through sufficiently rapid, the carbide will nearly all remain intact and go into solution in the melt, and a result is obtained similar to that when the molten metal is given an extended superheating treatment. That is, there is less undissolved graphite remaining in the molten iron. Such iron will then set under conditions of greater spontaneous temperature drops below the freezing point.

Dissolved gases seem to act in the same manner as an undissolved carbon content, for whenever I made vacuum melts, I noted the formation of eutectic structure developments. It would, therefore, seem advantageous to subject very highly superheated molten iron to jolting or centrifuging processes, and this for the reasons already given, and to be gone into additionally in what follows.

[84] *Monatshefte des Berliner Bezirkvereins deutscher Ingenieure*, No. 4, April 1, 1926.

Dilatometric Tests to Show Growth

In view of the constantly increasing pressure in steam engines and turbines, the production of a high-test, constant volume cast iron has assumed prime importance. For this reason, I have repeatedly conducted investigations to bring out the influence of graphite formation and production operations on the iron upon its tendency to "grow." The following experiments with a universal differential dilatometer, as designed by the metallurgical laboratory of the Institute of Technology of Aachen,[35] were conducted with temperature oscillations from 750 to 1830 degrees Fahr. (a rod of *chronin* of the same dimensions served for comparison). Each temperature oscillation (heating and cooling) extended over about two hours.

The initial heating, and the first three heatings that followed—conducted under best possible conditions of air exclusion—were recorded dilatometrically and photographed. The rods were then subjected 25 times to temperature oscillations, while in a vacuum, for the above mentioned period—the rods being isolated from each other and from the quartz heating tube by mica plates. These treatments were severally supplemented by two dilatometric registered and photographed oscillation operations while in a stream of nitrogen, and subsequently additional oscillation tests were conducted in the presence of air.

Operation of the Dilatometer

The coefficients of expansion of the rods of chronin and cast iron—the length of these being about 2 inches—gave a line, as the temperature increased, forming an angle with the horizontal of about 20 degrees for gray iron and about 50 degrees for a white cast iron. More marked deviations on the part of these angles *upward* indicated an increased expansion caused by "growing," or by the volume increase connected with the gamma/alpha phase change. Deviations *downward,* on the contrary, denoted a greater contraction in cast iron due to the equalization of internal casting strains, or came from the reversible alpha/gamma phase change occurring on heating. The kink in the

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[35] *Stahl und Eisen,* 1926, p. 142.

heating curves a little above 390 degrees Fahr., often observed, is caused by the magnetic reversal of the cementite. Such investigations on an iron with about 3.00 per cent carbon, and 2.20 per cent silicon, have shown that 25 oscillations in temperature from 750 to 1830 degrees Fahr., while in a vacuum, have brought about a practical cessation of growth, since subsequent oscillations in an atmosphere of nitrogen resulted in no further enlargement—in fact, often evidenced a slight reduction. However, as soon as air was allowed to enter, the growing was resumed. Nitrogen

Table 14

	Melt No. 1	Melt No. 2	Melt No. 3	Preheated Mold to Dry Sand	Dry Sand Mold to Green Sand	Green Sand Mold to Chill Mold
Total carbon, per cent....	2.99	2.98	2.85	2.85	2.87	2.90
Graphite, per cent........	2.02	1.89	1.81	1.81	1.81	1.75
Silicon, per cent..........	2.18	2.28	2.40	....	2.40	....
Heated at, degrees Fahr...	2,300	2,590	2,895	....	....	....
Poured at, degrees Fahr...	2,280	2,280	2,280	....	....	....
Structure	Coarse	Fine	Very Fine	Fine	Very Fine	Extremely Fine
Hardness before heating...	....	....	....	180	179	197
Growth in per cent after oscillations:						
1 and 3, in air..........	1.70	1.79	2.00	1.80	2.00	1.98
4 and 28 in vacuum....	3.71	3.99	3.20	4.00	3.20	2.80
29 and 31 in air........	0.49	0.79	0.41	0.60	0.41	0.69
31 and 33 in N_2........	0.10	0.00	0.11	....	....	....
Total growth	6.10	6.57	5.72	6.40	5.61	5.47
Hardness after heating....	180	175	185	....	....	....
Specific gravity	7.364	6.972	7.219	....	....	....
Composition after oscillation (33 & 31, respectively):						
Total carbon, per cent..	2.69	2.71	2.69	2.68	2.71	2.69
Graphite, per cent......	2.69	2.71	2.69	2.68	2.71	2.69

atmosphere treatment gave but very slight indications of growth, and only in several exceptional cases.

The original curves of three cases of cast irons of this kind, having compositions that are practically identical (compositions given in Table 14, melts 1, 2 and 3), and which were poured off after receiving increasing degrees of superheat, are given in Fig. 18. These are identical with the heats already mentioned above (cf. Figs. 4 and 5, and also Table 6), and are intended to illustrate the retardation of solidification below freezing temperature, in its relation to the temperatures of superheating.

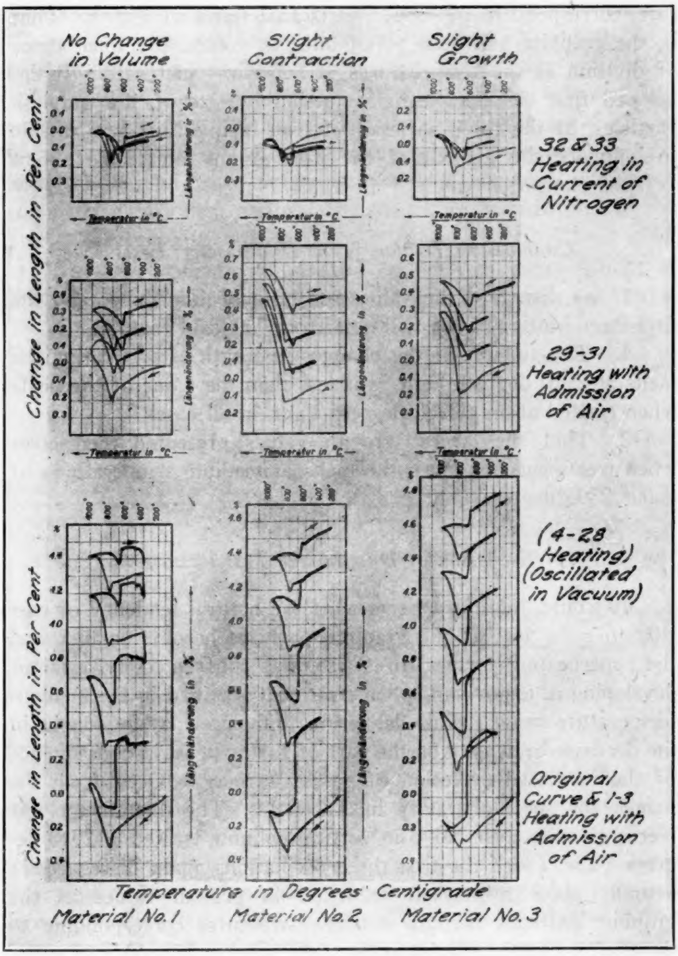

FIG. 18—GROWTH CURVES FOR A SILICON-RICH CAST IRON SUPERHEATED AT VARIOUS TEMPERATURES (ANALYSES OF TABLE 14)

The dilatometer test pieces were taken from the upper end of the dry-sand mold. Their structural conditions would, therefore, correspond to the upper horizontal series of Fig. 5. That is, the graphite had been precipitated in continually finer states of division as the temperatures of superheat increased. It developed that this increasing reduction in size of the graphite particles, of the three varieties of iron in question, was unable to influence the growth of the iron to any noticeable extent (cf. the elongation values [36] in Table 14).

Conclusions Drawn from Dilatometer Tests

If we disregard the values of the annealing curve and the first three heatings,[37] we will note from Table 14 that:

1. The amount of the changes in length after treating the melts at 2910 degrees Fahr. was less than the value of the heats when treated at only 2280 degrees Fahr. in all cases.

2. That the largest growth values presented themselves when treatment was given the melts at medium temperatures of about 2595 degrees Fahr.

Discussion of Dilatometer Test Results

It would, therefore, seem as if the natural tendency of cast iron to grow less as the graphite particles become smaller and the superheating temperatures rise, was confronted by a factor developing in opposition, when treatment was had in the medium temperature range. This deleterious influence may be sought in the decrease in density on the part of the material in consequence of the increased evolution of gases; as may be seen from the values for specific gravity in Table 14. The dilatometer test pieces given in melt No. 3 in vertical column, treated at 2910 degrees Fahr. (with the first three oscillations again disregarded) actually show a marked reduction in growth values as the graphite particles become smaller (structures corresponding to those of the vertical series at the right hand in Fig. 5). If atten-

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[36] It should be noted that Material No. 3 (the lowest curve on the right) was erroneously given an additional heat oscillation.

[37] Possible imperfections in the orientation of the apparatus became compensated for during the taking of the first few curves.

tion is paid to the fact that the lowest test in Table 14 (the three columns on the right) exhibits an increased supereutectoid carbide content favoring growing of the metal, the deduction can be made that with equal carbide content as in melts 1 and 2, their growth values would have fallen very considerably still. The total value of the expansions in the tests ranging between 5.47 and 6.57 per cent must, however, be considered generally as quite high. This has been caused by too high a silicon content in the melts, and hence an unsuited chemical composition of these melts have seriously reduced the benefit of a reduction in the size of the graphite particles.

Density determinations made on the test series poured at 2300 degrees Fahr., in vertical direction, gave values (cf. Table 15) which seem to indicate that as the rate of cooling decreases the density drops similarly—as shown by the specific gravity

Table 15

Transition from:	Graphitic Structure	Total Carbon	Graphite	Silicon	Specific Gravity	Hardness No.*
Preheated to dry sand mold....	Coarse	2.99	2.02	2.20	7.364	175–181
Dry sand to green sand mold...	Fine	3.02	1.97	2.18	7.229	173–180
Green sand mold to chill mold..	Extremely Fine	3.01	1.89	2.18	7.194	195–198

*Tested for hardness on upper and lower surfaces of the cylindrical test piece.

results. It may not be amiss to connect this phenomenon with the bettered opportunity for the evolution of gases as the rate of cooling is retarded.

Tests of Melting Methods

In order that the influence of this method of melting with abnormal superheating upon the volume constancy and resistance to corrosion might be tested upon such irons as those for cylinders, I prepared five test pieces, furnished me by large practically operated foundries—these not knowing what I desired them for—and later conducted growing tests under the differential expansion method. These test bars were cut longitudinally into four rods, the round section being divided into quadrants, and dilatometric test specimens were turned out of two such pieces from opposite quadrants, (as shown in Fig. 19). These

tests were carried through along the lines as explained previously as oscillation tests between temperatures of 750 to 1830 degrees Fahr., in air and in nitrogen. The individual test pieces were regularly weighed at the conclusion of every test, as also when the testing method was changed.

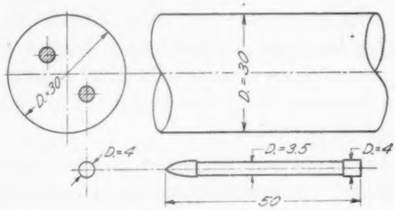


FIG. 19—ARRANGEMENT OF THE SPECIMEN AND MEASUREMENT OF THE DILATOMETER ROD IN MILLIMETERS

Table 16 itemizes the plant identification data, the physical strengths and the preparation of the specimens. The graphitic structures are seen in Fig. 20. The graphical representation of the oscillation values are shown in Fig. 21. The following may be deducted therefrom: The coarsely graphitic cupola irons of plants A and B, which ran 1.50 and 1.85 per cent in silicon, grew very markedly. The greatly superheated, high-test cast iron of plant B (B′), also carrying 1.85 silicon, but with much better

Table 16

	Establishment				
	A	B	B′	C	D
	Type of Iron				
	High Pressure Cylinder Castings	Piston Ring Castings	High Test Cylinder Castings*	High Test Low Carbon C. I.	Quality Castings†
Analysis, as received, in per cent:					
Total carbon	3.02	3.02	3.02	2.38	2.70
Graphite	2.44	2.70	2.42	1.69	1.84
Silicon	1.50	1.85	1.85	2.00	1.80
Manganese	0.85	0.65	0.92	0.80	1.50
Phosphorus	0.43	0.57	0.07	0.14	0.04
Sulphur	0.16	0.12	0.09	0.13	0.02
Type of furnace used	Cupola Normal Melting	Cupola Normal Melting	Cupola Hot Melting	Cupola Highest Superheat	Air Furnace High Superheat
Bending strength, pounds per square inch	66,850	65,575	76,805	83,630	103,830
Deflection, in inches	0.472	0.512	0.394	0.315	0.236
Graphitic Structure	Long Flakes	Long Flakes	Short, Thin Flakes	Mostly Granular	Short, Very Thick Flakes

*Same as B′ in text.
†Synthetic cast iron.

graphitic structures, grew to only one-half the extent (cf. also Fig. 22), in which the comparison between the two materials of plant B with, and without high superheat in melting is shown

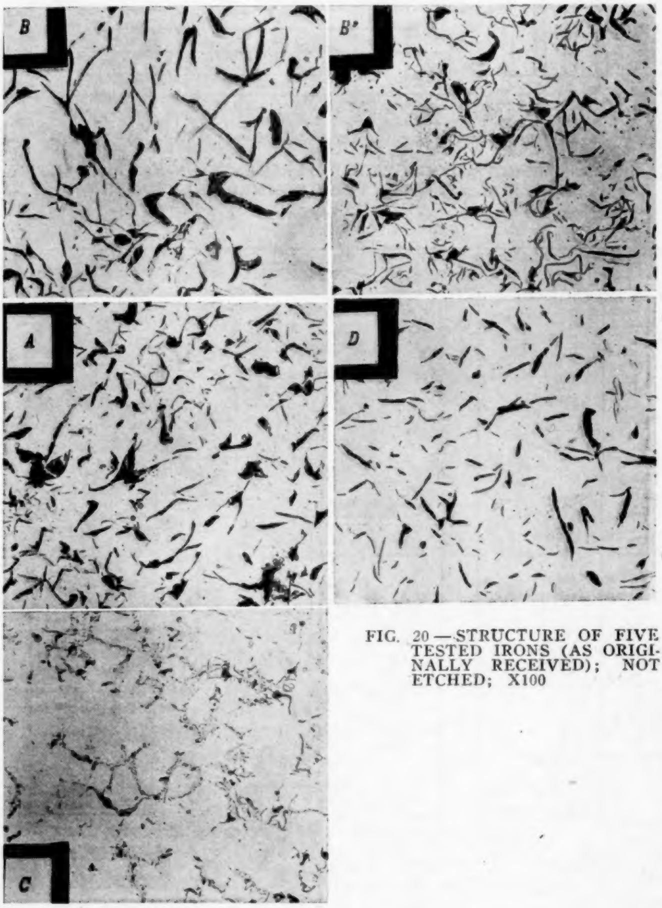
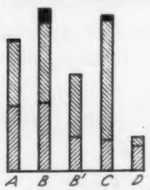


FIG. 20—STRUCTURE OF FIVE TESTED IRONS (AS ORIGINALLY RECEIVED); NOT ETCHED; X100

in the original curves. The best results were obtained with irons melted in the air furnace with heat regeneration and under abnormal superheat. This was made by plant D, and contained



	Per Cent Increase after Oscillation			Total Increase Per Cent
	1-3 In Air	4-28 In Vacuum	29-30 In Nitrogen	
A	2.09	2.00	0.09	4.18
B	2.19	2.50	0.49	5.18
B'	1.09	1.99	0.00	3.08
C	0.90	3.79	0.19	4.97
D	0.79	0.30	0.00	1.09

FIG. 21—RESULTS OF GROWTH EXPERIMENTS ON SAMPLES OF MATERIAL SELECTED FROM COMMERCIAL PLANTS

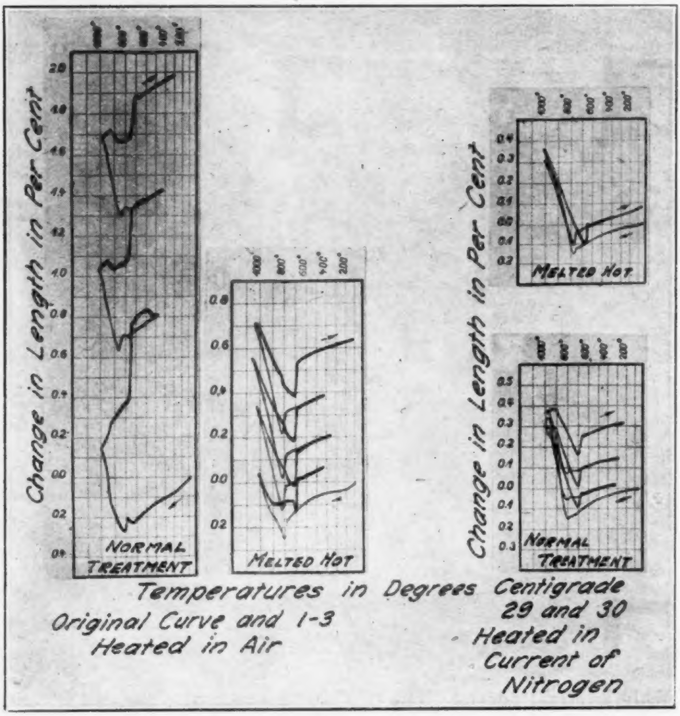


FIG. 22—INFLUENCE OF SUPERHEATING OF THE MELTED IRON UPON THE INCREASE OF GRAY CAST IRON

1.80 per cent silicon (see also Fig. 23). The iron of plant C, which was low in total carbon, with very finely divided graphite but high in silicon (this was 2.00 per cent), grew very slowly—this, however, amounting to considerable at the close of the oscillation tests. The following deductions can, therefore, be made from the above:

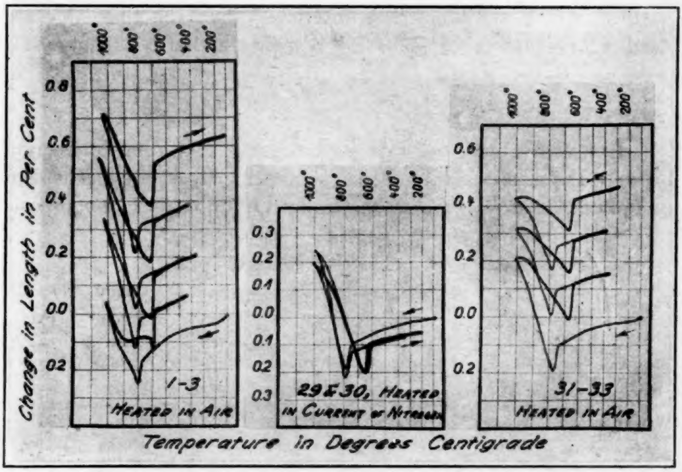


FIG. 23—GROWTH CURVES OF HIGHEST SUPERHEATED MATERIAL FROM PLANT D DURING 33 OSCILLATIONS

1. The very best graphite structure results (plant C) can be rendered illusory by too high a silicon content.

2. Lowering the total carbon cannot balance the tendency to grow as the result of high silicon. (Evidently this iron was not superheated sufficiently—compare with item 4 below).

3. A low silicon content (plant A) is by no means a guarantee that the iron will not grow under the oscillation test, if by reason of insufficient superheating of the molten metal the character of the graphite developed is still too coarse and (most probably) a serious evolution of gases has not affected the density of the material injuriously.

4. When sufficiently superheated, even a silicon content of 1.70 (plant D) to 1.80 per cent (plant B′) is allowable in obtaining a relatively constant volume material.

The graphite structure of the material of plant D may be considered as favorable, although the size of the particles in this case has not been decreased to that of extreme fineness. The graphite in question developed into compact (broad) but short needles, which are much less interlaced than the thin, delicate needles of graphite of plant B (B′ being higher-test iron).

Relation of Graphite Size and Growth

It is, therefore, possible to recognize a certain connection between the relative graphite size arrangement and the mechanism of growth, at least as far as the irons of practically like composi-

Table 17

	Plant A	Plant B	Plant B	Plant C	Plant D
Pearlite in field of view:					
Iron, as received, per cent......	100	85	100	100	100
After 4 oscillations, per cent...	40	40	50	75	95
After 31 oscillations, per cent...	10	10	30	10	90
Phosphide, per cent..............	5–10	Little	Very Little	Very Little	Traces
Per cent growth:					
After 4 oscillations............	2.09	2.19	1.09	0.99	0.79
After 31 oscillations............	4.18	5.18	3.08	4.97	1.09
Weight change, in per cent, as compared with original iron:					
After 1 to 3 oscillations......	+0.243	+0.213	+0.201	+0.168	+0.204
After 4 to 28 oscillations......	—0.254	—0.190	—0.221	—0.194	—0.204
After 29 to 31 oscillations......	—0.223	—0.065	—0.154	—0.178	—0.008
Per cent contraction in liquid air..	0.151	0.173	0.066	(*)	0.056

*Not determined.

tion of plants A, B and D are concerned. It is still more patent to connect the above discussed observations made in the preparation of these varieties of cast iron with different melting methods, particularly with increasing degrees of superheating temperatures which will have effected the total disappearance of the graphite nuclei in the matrix. More particularly, however, will the effect have been directed toward the beneficial increase in density on the part of the molten irons, as these could resist the counter-pressure incident to the increase in volume coming from the carbide disintegration much better. As a matter of fact, this connection between carbide disintegration and growth may easily be recognized in Table 17.

Experiments to Determine Counter-Pressure Effect

The following instance will illustrate how intensely the counter-pressure—that is the increased density—can exert itself in hindrance of the carbide disintegration: An eleven-pound melt of Swedish charcoal iron was alloyed with about 3.5 per cent silicon and then superheated to 2885 degrees Fahr., kept at this temperature for 15 minutes and then allowed to cool until the first indications of setting metal appeared on the surface. At that instant the melt was transferred to a furnace heated to

FIG. 24—MICROPHOTOGRAPH OF SWEDISH CHARCOAL IRON. SUPERHEATED TO 2,885 DEGREES FAHR. COOLED TILL FIRST FREEZING SHOWED THEN PLACED IN FURNACE HEATED TO 2,010 DEGREES FAHR. COOLED IN ONE AND ONE-HALF HOURS TO 1,920 DEGREES FAHR., THEN AIR COOLED. SHOWING COARSE GRAPHITE NEEDLES AND LEDEBURITE PARTIALLY DECOMPOSED TO FINE GRAPHITE

2010 degrees Fahr. and allowed to remain in it 1½ hours with the temperature gradually lowered to 1920 degrees Fahr. The final solidification was effected in the atmosphere. In spite of the high carbon and silicon content, and in spite of the action of the nuclei of the kish-like graphite, the solidified iron contained considerable Ledeburite. The analysis of the melt gave the following: Total carbon 3.90, graphite 2.24, silicon 3.25. The structure of the metal is shown in Fig. 24. In addition to

coarsely crystalline kish-like graphite, there will be noticed Ledeburite which has been partially decomposed to finely divided eutectic graphite. If we realize that E. Schuetz[38] poured his iron containing about 3.50 per cent silicon into chill molds and obtained a pure ferrite-graphite-eutectic structure, then the enormous counter-pressure in our case, in view of the very slow cooling, must have prevented the total disintegration of the carbide. Since our melt came to solidification extremely slow and without practical differences in temperature between rim and interior of section, and since but few gases were present in view of the high silicon content and high degree of superheat with a consequent very light anticipated opening of structure at the moment of set, the actual freezing took place under conditions of such great density, that the incipient decomposition of Ledeburite resulting from the highly increasing counter-pressure due to the dilatometric effect of the carbide disintegration, was arrested.

Application Limitation of Oscillating Test

The rapid growth of the low total carbon iron of plant C, particularly toward the end of the oscillations showed very plainly that even when of the finest graphite structure, it could not stand up under the high heat-treatment involved in the oscillation test, if the balance of the chemical composition and the degree of superheat given were not adapted therefor. Probably the oscillation test at such high temperatures will be rejected if applied for the valuation of the usefulness of the five varieties of cast iron for steam and Diesel engines, because it is entirely too severe. An oscillation test with upper limits of temperature about 1290 to 1380 degrees Fahr. would seem sufficient, to obtain values that will be characteristic and allow satisfactory conclusions as to the service value under practical operation to be drawn. Naturally, a material which has stood up under such a "fire-test" will undoubtedly be all the more safe in service. On the other hand, where it is desired to judge a material particularly required for heat resistance, the oscillation test at such temperatures will be advantageous.

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[38] *Stahl und Eisen*, 1925, p. 144.

Growth in Vacuum

Tables 14 and 17, as also Fig. 21 showed that a marked growth had taken place when the 25 oscillations had been conducted in vacuum. As already stated in a previous publication[39], this again corroborates Kikuta's theory of the opening up of the structure of a material through mechanical stresses which appear in consequence of temporarily displaced dilatometric effects at Ac_1 or Ar_1 caused by the ununiform solution and precipitation processes of the several forms of carbon. Moreover, the phase change in the ferritic structure portions of a cast iron rich in silicon occurs at considerably higher temperatures[40] than in the parts containing carbon (pearlite or fine temper carbon). Hence, a gray cast iron with a single structure matrix will serve best for heat-resisting purposes, when:

Uniform Matrix Iron

1. The structure of this matrix is entirely *pearlite* to which additions have been given assuring the permanence of the carbide, as for instance by using chromium.

2. The structure is entirely *ferritic,* with the silicon content held so high that even under the highest temperature conditions of service, the phase change is not reached (heat-resistant cast iron, according to E. Schuetz).

Growth in Nitrogen

The high-test cast irons of plants B (B′) and D have already been shown (from Fig. 21) not to have grown in an atmosphere of nitrogen. They have consequently attained their final stage of structure opening sooner than the specimens from plants A and C, which continued to grow in an atmosphere of nitrogen, even though very little. This, while the coarse-graphite material of plant B (piston rings) kept on elongating visibly. In connection with the nitrogen treatment of the material from plant D (Fig. 21 to the right) there was added another air treatment to show

[39] *Stahl und Eisen,* 1925, p. 1173.
[40] P. Oberhoffer and H. Esser: Contributions to the Knowledge of the Binary Systems: Iron-Silicon, Iron-Phosphorus, Iron-Manganese, *Werkstoff-Auschuss Bericht des Vereins deutscher Eisenhuettenleute,* No. 69.

that in spite of having reached the final stage while in vacuum, the material promptly began to grow again as soon as oxidation phenomena intervened. (Cf. the corresponding original curve of Fig. 23).

The figures for the weight-changes of the several samples brought about by the oscillation heatings (cf. Table 17), indicate: (1) That growth in the presence of air was accompanied by a progressive oxidation (increase in weight). (2) That in vacuum there occurred a loss in weight by reason of the almost total reduction of the oxide, and conversion of the corresponding carbon in gas. The partial weight increase in an atmosphere of nitrogen (particularly the sample of plant D), without an appreciable concommittant change in length appears to me to be connected with a surface nitration of the sample.

Effect of Heating in Oil and Cooling in Liquid Air

Finally, twenty oscillations were carried through with the reserve test pieces made of the materials of plants A, B and D, between temperatures of rapeseed oil at 570 degrees Fahr. and liquid air at —300 degrees Fahr., allowing an immersion in these media of 5 minutes each time. In every case this treatment effected a contraction in the test piece (see Table 17). It can hardly be accidental that the material of plants D and B (B′), which were melted very hot, should have contracted but one-third as much as the samples from plants A and B (piston rings). The contraction probably resulted from the equalization of casting strains. Unfortunately, it was neglected to heat these test pieces to only about 750 degrees Fahr. and measure the contraction resulting *before* immersion in liquid air was resorted to. Hence it is not clear whether the treatment under extreme cold had anything to do with the reduction in length experienced. The figures are, however, applicable in *every instance* as a characterization of the *volume constancy.*

The real purpose in carrying out the oscillations between hot oil and liquid air was to follow up the influence of clear-cut heat and cold stresses upon an eventual opening up of the structure; phase-changes and (carbide) disintegration being excluded. This

Table 18

COMPOSITION OF SPECIMENS TREATED WITH STEAM
(ACCORDING TO K. SIPP)

Curve No.	Composition in Per Cents C	Si	Mn	P	S	Per Cent T.C. + Si
1	3.28	2.79	0.56	1.15	0.084	6.07
2	3.53	1.74	0.66	0.50	0.076	5.27
3	3.20	1.11	0.79	0.40	0.154	4.31
4	3.57	0.44	0.08	Sp.	0.014	4.01
5	2.93	0.94	1.20	0.23	0.070	3.87
6	3.12	0.62	0.94	0.22	0.070	3.74*

*1.0 per cent Nickel.

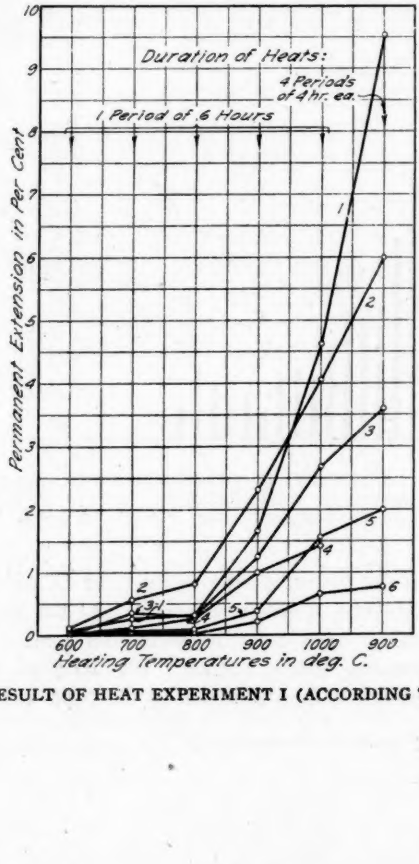
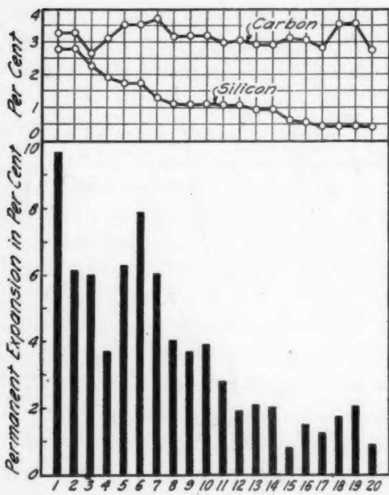


FIG. 25—RESULT OF HEAT EXPERIMENT I (ACCORDING TO K. SIPP)

could, therefore, not be observed. In the meantime, a publication by K. Sipp[41] has again brought out proof that, so far as chemical composition is concerned, the height of the silicon content has an astonishing effect upon growth.

Effect of Silicon on Growth

Fig. 25 illustrates the results of such a test series by K. Sipp. The permanent percentual expansions as resulting from an anneal at increasing temperatures during a period of six hours each are recorded therein. The composition of these melts, cor-



Number	Melt	Per Cent Silicon	Per Cent Carbon
1	I 1	2.79	3.28
2	II 1	2.79	3.28
3	III 3	2.28	2.67
4	III 1	1.92	3.11
5	I 2	1.74	3.53
6	II 2	1.74	3.53
7	III 2	1.30	3.72
8	III 4	1.12	3.19
9	I 3	1.11	3.20
10	II 3	1.11	3.20
11	III 6	1.09	2.99
12	III 5	1.08	3.07
13	I 5	0.94	2.93
14	II 5	0.94	2.93
15	I 6	0.62	3.12
16	III 7	0.58	3.08
17	II 6	0.45	2.82
18	I 4	0.44	3.57
19	II 4	0.44	3.57
20	II 7	0.41	2.74

FIG. 26—SHOWING PERMANENT EXPANSION AS TO SILICON CONTENT (ACCORDING TO EXPERIMENT OF K. SIPP). HEATED FOUR TIMES TO 900 DEGREES CENT. FOR FOUR HOURS

responding to the figures of the melts I_1 to I_6, of Fig. 26, are shown in Table 18. It will be observed that the growth curves in Fig. 25 follow each other in succession somewhat like the series of decreasing silicon content. Fig. 26 gives a tabulation of all the growth values obtained by K. Sipp for a 16 hour

[41] Will appear shortly in *Giesserei-Zeitung.*

anneal at 1650 degrees Fahr., of various compositions, and arranged under a descending scale of silicon content. The relation between the silicon content and the permanent expansion are

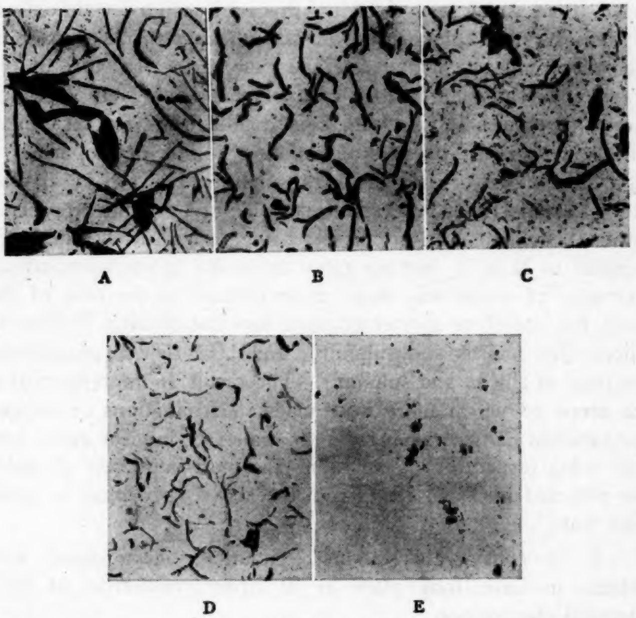


FIG. 27—CONDITION AND ANALYSES OF SAMPLES TREATED WITH STEAM. MICROGRAPHS (UNETCHED, X100) SHOW STRUCTURE: A OF MELT I, B OF MELT II, C OF MELT III, D OF MELT IV, E OF MELT V. ANALYSES AS LISTED BELOW:

	Melt I	Melt II	Melt III	Melt IV	Melt V
Carbon, per cent	3.55	3.04	2.89	2.98	3.42
Graphite, per cent	2.78	2.03	1.73	1.64	0.06
Silicon, per cent	2.13	1.08	0.97	1.14	1.00
Manganese, per cent	0.50	0.43	0.46	0.47	0.48
Sulphur, per cent	0.03	0.03	0.03	0.12	0.03
Phosphorus, per cent	Sp.	Sp.	Sp.	Sp.	Sp.
Chromium, per cent	...	...	...	...	1.12

brought out very clearly. An attempt to arrange the figures in accordance with a descending scale of total carbon gave no indication of a clear correlation existing.

Effect of Superheated Steam

In connection with a further series of investigations[42] on the behavior of various classes of cast iron held under steam at 570, 660 and 840 degrees Fahr. for 75 hours, the author made observations which seem to fit into this subject to a certain extent. Fig. 27 gives the compositions of 5 synthetic iron melts made in a small crucible, as also an average view of the structure of the graphite development in each case. Apart from Melt V, which carries chromium and set with a practically white fracture, there will be recognized the less favorable graphitic development of high silicon Melt I and the high sulphur Melt IV, as against Melts II and III. The graphite lamellae in IV, while appearing rather thin, make up for it by being longer, well interlaced (similar to Melt I), but are more accessible to corrosive action. Entrance of steam was made more difficult in the case of the thick, but therefore shorter graphite lamellae of Melt II (low in silicon, phosphorus and sulphur), and III (rich in phosphorus but poor in silicon and sulphur). The result of the tests, within the scope of which there were made determinations of oxygen and residual matter, taken from the scale-free interior metal (the skin being turned off), gave values the most important of which are collected in Table 19. From the above, there may be gathered that:

1. A considerable surface oxidation, accompanied with volume increase, took place in all irons irrespective of their chemical composition.

2. With steam at temperatures of 660 degrees Fahr., an appreciable oxidation of the heart of the metal took place only in the case of the melts richer in silicon and having a poorer graphite development.

3. With steam treatment at 840 degrees Fahr. the corrosion (oxidation) in the heart of the iron samples rich in silicon and sulphur (with poorer graphite development) was greatly increased, while in the heart of the lower silicon iron of Melts II and III (rich in phosphorus), by reason of their better graphite development, remained practically free from oxide formation. The beneficial effect of a dense structure is shown particularly in

[42] Complete report in *Die Giesserei,* 1926, July 3.

Table 19

Heat Treatment in Steam, at 570 Degrees Fahr.	Weight Increase in Per Cent After Steam Treatment	Per Cent Change in Volume by Steam Treatment	Per Cent Weight Loss Through Chemical Reduction by KOH and Zinc Dust	Oxygen Values of the Oxide—Heart of the Metal: Extraction Method	Oxygen Values of the Oxide—Heart of the Metal: Chemical Method	Change of Graphite and Total Carbon in Per Cent Through Steam Treatment: Total Carbon	Graphite	Combined Carbon
I	0.41	....	0.88	0.054	.....	3.44	2.72	0.72
II	0.38	....	1.20	0.029	.....	2.94	1.92	1.02
III	0.25	....	0.57	0.022	.....	2.85	1.71	1.14
IV	0.23	....	0.60	0.045	.....	2.95	1.63	1.32
V	0.27	....	0.69	0.005	.....	3.40	0.08	3.32
660 degrees Fahr.:								
I	0.85	....	1.28	0.163	.....	3.37	2.70	0.67
II	0.70	....	2.00	0.033	.....	2.84	1.85	0.99
III	Not Given	....	Not Given	Not Given	.....	Not Given	Not Given	Not Given
IV	0.64	....	1.26	0.043	.....	2.90	1.63	1.27
V	0.82	....	2.25	0.008	.....	3.31	0.14	3.17
870 degrees Fahr.:								
I	2.80	10.2	6.9	0.684	0.736	3.09	2.79	0.30
II	1.93	4.4	5.0	0.053	0.070	2.83	1.87	0.96
III	1.86	4.2	4.7	0.051	0.093	2.71	1.99	0.72
IV	1.89	6.6	3.4	0.422	0.502	2.73	1.73	1.00
V	1.72	5.4	4.2	0.015	0.059	3.08	0.21	2.87

Melt V, which contains chromium and which set with a white fracture.

4. A much greater degree of carbide disintegration took place in a current of steam—with some air admission—at 570 to 840 degrees Fahr., than has generally been observed heretofore.

5. A loss of 10 to 15 per cent in total carbon is to be recorded as the result of the steam treatment of the cast irons.

As a result of observing the changes in structure, attention is directed to Fig. 28, which shows the progressive oxidation along the graphite lamellae beginning at the edges—Melt I.

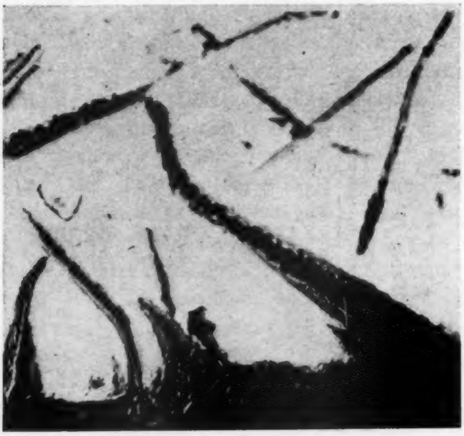


FIG. 28—NOT ETCHED, X500

However, the graphite lamellae situated further inward, which observation shows have no longer any connection with the surface metal of the test pieces, often show the same oxidation phenomena.

Iron for Steam Castings

Even though there exist many single instances of observations regarding the behavior of cast iron under steam service conditions, the literature of the subject is unfortunately very inadequate as yet, and particularly far from being systematic. Nevertheless, my few observations along this line would indicate

Table 20

EXPERIMENTS ON THE INFLUENCE OF NICKEL-CHROMIUM ADDITIONS UPON THE QUALITY OF VARIOUS SYNTHETIC CAST IRONS (BY PIWOWARSKY)

	Melt No.								
	1	2	3	14	15	16	17	18	19
	Iron Mixture								
	A[1]	A	A	A	A	A	A	B[2]	B
Chemical composition, in per cent:									
Total carbon	2.54	2.30	2.20	3.45	3.40	2.59	2.56	3.02	2.00
Graphite	2.02	1.65	1.28	2.71	2.65	1.79	1.79	1.91	0.99
Silicon	2.46	2.64	2.35	1.92	1.76	2.32	2.02	1.64	1.84
Manganese	1.06	1.40	1.19	....	....	....	....	....	....
Phosphorus	0.18	0.14	0.16	....	....	....	....	....	....
Nickel	....	0.27	0.71	....	1.02	1.01	1.18	0.82	0.82
Chromium	....	0.85	1.40	....	0.34	0.30	0.29	0.08	0.06
Bending strength, pounds per square inch	87,185	100,985	88,180	49,780	62,580	96,715	96,715	71,115	52,625
Deflection, in inches	0.433	0.354	0.315	0.433	0.866	0.866	0.335	0.453	0.335
Compression strength, pounds per square inch	163,565	176,365	184,900	n. o.	n. o.	n. o.	n. o.	n. o.	n. o.
Tensile strength, pounds per square inch	44,230	50,490	44,945	25,500	27,025	46,935	39,825	35,555	25,500
Impact strength, work in foot pounds	10.85	7.23	8.68	n. o.	n. o.	n. o.	n. o.	n. o.	n. o.
Hardness No.	179	223	245	162	188	222	247	216	234
Number continuous blows	n. o.	n. o.	n. o.	814	1,659	15,156	4,771	1,661	87
Temperature data—melting and pouring	(*)	(*)	(*)	(†)	(†)	(†)	(†)	(‡)	(‡)

[1] Swedish charcoal iron + scrap + synthetic Mayari composition iron.
[2] Swedish charcoal iron + scrap + Mayari pig iron.
n. o. Means not observed.
*Heated to about 2,730 degrees Fahr.; poured at 2,640 degrees Fahr., in dry-sand molds.
†Heated to 2,910 degrees Fahr.; poured at 2,550 degrees Fahr., in dry-sand molds.
‡Heated to 2,910 degrees Fahr.; poured at 2,640 degrees Fahr., in dry-sand molds.

that it seems possible to produce a cast iron capable of resisting steam even at very high temperatures. Such an iron will have to be made of a suitable chemical composition based upon a systematic reduction in the size of the graphite particles contained, with full relief from occluded gases and a deoxidation of the melt. As a consequence, this treatment will be chosen not only because of better physical strengths of the material, but also to produce castings free from strains and of constant volume. Only when I applied treatment with strong solvents, such as dilute acids, etc., did I *not* find a marked advantage due to a finer graphite structure content.

Special Alloys

In a comprehensive paper[43] on the influence of a series of alloying metals (nickel, chromium, aluminum, vanadium, tungsten, molybdenum and cobalt) the author has shown that the influence of special metals in cast iron will only get full value when recourse is had to appropriate heat treatment (annealing, benefication processes); further, that it is illusory to expect an improvement possible in the pearlitic structure matrix, so long as the problem of systematic increasing the fineness of the graphite particles has not been solved. The present, with the systematic reduction in the size of the graphite particles fully at our command, would seem the proper time to renew our investigations into the effect of alloying cast iron. A glance at Table 20 indicates that some experimental melts of the author intended to bring out the influence of nickel-chromium additions (using these synthetically and also in form of mayari pig iron) for a possible quality increase in various high carbon varieties of cast iron, could not effect appreciable benefits when the irons had already been transformed to high-test metals, through abnormally high superheating. Of course, the few values in question cannot be considered as conclusive evidence, but they seem to substantiate my previous suppositions that (apart, possibly, from resistance to abrasion) the influence of small percentages of beneficating additions to ordinary cast iron hardly shows up in the resulting physical properties, and only obtains

[43] *Stahl und Eisen*, 1925, Feb. 26, p. 289.

full value when an additional adequate heat-treatment has been given the metal, just as we may observe in the case of the special steels. None the less, it is desirable that investigations into the further improvement of high-test cast iron should continue, in order that all the value there is in the material shall be brought to light. This, particularly, because in addition to the already permanent competition of the steel casting, gray iron will have to contend with the more recently appearing very dangerous competitors in form of the light-metal alloys (for instance, the aluminum-magnesium alloys). These light alloys are already developed to strengths up to 56,890 pounds per square inch tensile, with 10 per cent elongations.

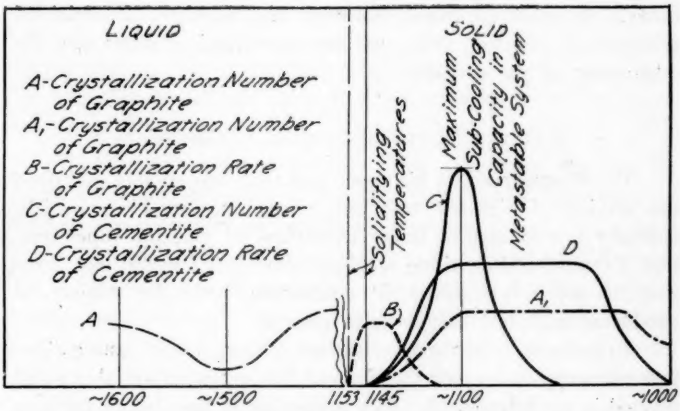


FIG. 29—CRYSTALLIZATION DIAGRAM

Crystallization Theory

As the concluding part of my paper, I would point out the crystallization diagram of cast iron (Fig. 29) which I have constructed upon the basis of well known investigations (such as those of von Ruer and his collaborators) as well as those of my own. Naturally, their value is only qualitative, since I have not undertaken to actually measure the absolute size of the nuclei, as well as the crystal formation rates. The explanation and application of this information will be patent to every

metallurgist. The absorption of the nuclei by the molten metal when this was abnormally superheated is a deduction I made as the result of my observations, and I did not differentiate between finely divided mechanically dispersed "seeds" and spontaneously formed "nuclei" of graphite (because of the processes of disintegration involved). Furthermore, it should not be inferred from the diagram that I am an unconditional adherent of the double-diagram theory (iron-carbon, i.e., iron carbide), simply because in it I use the expressions "number of nuclei" and "rate of crystallization." All we have to do is to replace the expression "rate of graphite crystallization" (Line B in diagram) by "rate of disintegration of the carbide," and we are in accord with those who are unconditional adherents of the single-diagram theory today. In such an event, however, the number of nuclei of graphite (A_1 in Fig. 29) must be understood to mean the disintegration of the carbide.

Written Discussion by Dr. F. Greiner*

Dr. Piwowarsky, in his paper just read, has so ably described the making of high-test cast iron by melting suitable materials, specially low in carbon, under conditions of extreme super-heat, that I cannot add anything to his statements. I would like, however, to say a few words in connection with the subject of producing high-test cast iron in general.

In order to hold the total carbon content in the castings low, it is necessary to so melt the charges that extra carbon above that wanted is not introduced. This is possible in the electric furnace, as also in the newly invented Wuest furnace—an oil-fired air-furnace and charging stack with pre-heated air for combustion—heat for this being obtained recuperatively from the waste gases. The furnace is described in *Stahl und Eisen* No. 35, 1925, is patented in all countries and is built in several sizes, up to three tons an hour capacity; the melting operation being continuous. The advantage of continuous operation over batch melting in larger tonnages is obvious and need not be gone into here.

For purposes of producing low-total carbon cast iron steel and wrought iron scrap, with the necessary coke for recarburiza-

*Stuttgart, Germany.

tion purposes only, are charged in alternate layers at the far end of the furnace in the charging shaft. As melting proceeds and the liquid metal collects in the hearth of the furnace, it becomes superheated to the degree desired by suitable firing with the fuel oil used. Since it is necessary to also provide the required silicon and manganese, these are charged with the steel and recarburization coke. Charging these elements in required quantity in pig iron is not advisable, as this introduces phosphorus and sulphur. Again, the use of ferrosilicon and ferromanganese direct exposes them to severe oxidation and the results would be unreliable. Hence the use of specially prepared briquettes of the ferroalloys with cement as the binding material, which prevents all oxidation until actual melting, when mixing with the other molten material takes place, and a definite predeterminable composition is had. These briquettes are also covered by patents universally, and the extent of their use on the European Continent may be judged by the fact that up to date some 30,000 tons have found their way into foundries successfully.

It is not my intention to serve as an advertising medium for furnace and briquettes, but I do wish to show my brother-foundrymen of America how we are going about to produce very high grade material in the gray iron foundry, and do so with economical costs. Our European methods may not be possible of direct transfer to your conditions in every respect, for you have an advantage in comparatively cheap high silicon pig irons; but in the production of the material under consideration, with practcally all steel mixtures, the furnace and ferroalloy briquettes certainly seem to fill the bill best.

Discussion

Following the presentation of this paper by Dr. Richard Moldenke, Dr. Moldenke then offered to translate any question in discussion of the paper to German for Dr. Piwowarsky, as well as convert his German reply to English for the meeting.

R. S. MacPherran: Would it be possible that part of the superiority of electric furnace iron is due to this same superheating of cast iron as discussed in this paper?

Dr. R. Moldenke: Dr. Piwowarsky says you are perfectly right in that supposition, and you will find some figures on this in the paper bearing on that point.

J. T. MacKenzie: Along the line of Professor Piwowarsky's very important announcement which appeared some months ago, I would like to state that I think this discovery has explained more things to the foundrymen than anything that has come out in a good many years. If you will remember, Elliott in his work on the electric furnace, and all the rest of us who have worked with the electric furnace found that it took from 0.30 to 0.70 per cent more silicon in electric furnace iron than in cupola iron to get the same amount of graphite. We have been wondering for years why the addition of steel to a cupola charge made a difference in the strength of the iron which could not be explained by the carbon content or by any other elements of the analysis. I think the explanation is right here, that when we put steel in the cupola, we have to melt it extremely hot to get it out at all. Since it had no graphite to start with, our strength obtained from steel can be very well explained on this basis. I do not think, though, from the paper, that Dr. Emmel has quite gotten his carbon control as close as we might wish. I notice a variation from 2.32 to 2.86 in his heats. Dealing with such low carbon material, a little further refinement in the process would be very desirable.

Again in the matter of the high pressures developed in this iron as mentioned on page 967, I cannot quite see why Professor Piwowarsky thinks he got such enormous pressures in slowly cooled iron. A great many people are annealing castings for the purpose of relieving strains. It doesn't seem to me that a casting cooled so slowly would be able to develop any internal strains.

I feel that Prof. Piwowarsky cannot be too highly complimented on this paper and that his work has supplied the most important generalization on cast iron of the last decades.

Dr. R. Moldenke: Dr. Piwowarsky says that the basis of this high temperature melting and superheating is the breaking up of the iron carbide. When this breaks up there is an expansion of about 3 per cent in the metal. If you cool quickly, you get a setting on the outside and may have a pipe within; whereas if you cool very slowly, the whole of the metal sets at about the same time and when this expands you get that pressure. The old rule of the foundryman, to melt as hot as you can, let the iron stand or put some sprue in it to cool it down, is again vindicated. It is exactly what Dr. Piwowarsky is teaching us now and given us the proofs.

J. W. Bolton: It is particularly significant that in European foundry practice, at least as seen from the English and German results that we have heard in the last few days, that the production of high quality iron is more common abroad. It is particularly significant that this production

has gone hand in hand with the so-called theoretical method of approach. In this paper Dr. Piwowarsky, in an excellent treatise, brings forth in an applied fashion many of the simpler laws of physical chemistry. Dr. Piwowarsky has simply applied the laws of germination and grain growth to cast iron. In other words, it has started from an academic point of view and he has gotten real and honest practical results.

Mr. MacKenzie just spoke of the explanation afforded in this paper of the action of steel in charges of electric furnace iron. In the last few years there have been presented before the A. F. A. several papers dealing with numerous tests which showed various relationships between composition, structure and the strength properties, when determined on ordinary cupola iron. No matter who the investigators were—there have been possibly a dozen—the results of some simply check those of the others. However, lately in attempting to analyze some electric furnace work by Williams and Terry, by the late George Elliott, and others, and in attempting to correlate the properties of semi-steel as compared with gray iron, we found these average curves, which worked very well for ordinary cupola iron, fell down.

There is another point brought out here that possibly will be of great practical interest to American foundrymen, and that is the question of chill in sand cast irons. Dr. Piwowarsky says that if you get the carbon entirely dissolved, it takes more time for it to grow on re-cooling. In chilled cast iron we have a large proportion of the carbon dissolved. In sand cast iron a large percentage of it is precipitated. On page 956 of Dr. Piwowarsky's very interesting paper you have this paragraph:

"I have therefore proposed a simple process of producing high grade cast iron in which all irons, even those with high silicon content, should be specified from the blast furnaces as chill cast irons, and even water quenched, if possible, regardless of their composition in the molten state.

The significance of this, I think, is easily apparent.

J. T. MacKenzie: Mr. Chairman, right at that very point I would like to ask a question. Has it been tried? We find as a general rule that a chilled pig, on account of its low melting point, is rather difficult to melt as hot as the same pig if it is sand cast, and I wonder what the practical difficulties will be when the two opposing forces meet.

Dr. R. Moldenke: No matter how hot Dr. Piwowarsky melts, if necessary he increases the superheat afterwards in another furnace. The "duplexing" process does just this, first melting in the cupola, and then the temperature much increased in the electric furnace. If you take chilled iron which is water cooled in addition you get better results with it. Dr. Piwowarsky states that he got a very much stronger iron in the end results by taking a chilled, water sprayed pig iron in the first place and melting directly in the electric furnace.

J. W. Bolton: In this country we have not noticed any difference in strength between castings for chilled cast and from sand cast irons. Has Dr. Piwowarsky found any differences between the chilled cast iron and the sand cast in the older time cupola practice? I may say that we have not.

Dr. R. Moldenke: Dr. Piwowarsky states that when they used the chilled pig they got greater strength in their resulting castings than with sand pig. But, as you know, over there they melt with very much smaller cupolas than we have over here. A three foot diameter cupola is their usual size and that may account for differences in results.

E. J. Lowry: Is it not because our chilled cast pigs over here are pretty large? Over there their chilled pigs are much smaller.

Dr. R. Moldenke: Dr. Piwowarsky says that the tests were made of particularly small pigs over there, one cast in sand and one cast in chill, and then melted afterwards, and they noticed quite a difference in strength results.

C. A. Hansen: We are talking here considerably about the possible differences between sand cast and chilled cast pig as they go through a cupola. One of the things that has interested me most mightily, and it seems to have interested all those others whom I have talked to about the subject, is the fact that the Germans claim, at least, to be melting irons in the cupola and bringing out carbons down around 2.40 to 2.60 and at 1550 to 1600 degrees Cent. I believe Emmel gives one analysis as low as 2.32. But whether he can get 2.30 continuously, I doubt very much. But supposing you get down to 2.60 continuously, and bring out metal at 1500 degrees Cent. and better at the spout, he is so far above the melting range of either sand or chill cast iron that I should think this difference was pretty well blotted out. The highest temperature I have ever seen in a cupola in the United States, and I haven't seen them anywhere else, is 1520 degrees Cent. That has been pretty well substantiated. That is about 2750 degrees Fahr. I don't mean just an erratic high temperature but a temperature of 1520 to 1540 Cent. maintained throughout the entire heat.

Dr. R. Moldenke: Dr. Piwowarsky says those temperatures were actually obtained, and that there were sworn members of the patent office present to be sure of the actual facts, as the patents are based on high temperature results.

C. A. Hansen: I would like to say this from observation. Our company operates 17 different foundries, and we try to spread the work in such a way that each foundry gets more or less of one general type of work to do, so that it can accommodate itself to that work. In one of the foundries we are doing a considerable amount of specialty work, refrigerator

castings that absolutely must be sound all the way through; flow meter bodies, and very intricate castings that are very difficult to get and get sound. Here we have consistently found that if our cupola spout temperatures get down to under 1420 degrees Cent. it reduces our scrap losses. If we can keep our temperature under 1460 degrees Cent. we have almost no rejection due to shrinkage strains, shrinkage cavities or porous castings generally. All of these castings are tested under hydraulic pressure. We would like very much to operate at higher temperatures in these cupolas, but at the same time we want to keep our metal a cylinder iron composition. We want our carbons as low as we can get them. The best we can do regularly is around 3.00 to 3.2 with silicon 1.8 to 2.0. We can get metal hotter at the spout by cutting our blast volume, in addition to boosting our coke ratio; but to slow down a cupola by giving it less air and more coke to burn per ton of iron melted, leads to absorption of carbon in three different ways. First, you have more carbon from the coke to dissolve by having a higher coke column for the metal to percolate down through, which leads to high carbons. You next have a slower melting rate, which gives more time for the metal to pick up carbon from the coke. Finally, you have hotter metal, which also increases the tendency for the metal to pick up carbon from the coke column. And it has been my experience in checking up one cupola after another that as the blast rate goes down and as the coke ratio goes up, the spout temperatures increase. When you get over 1500 degrees Cent. I have never seen metals that are not hypereutectic. They have reached virtually the saturation content of carbon. That means carbons around 3.5 or 3.6 for irons containing 1.8 to 2.1 silicon.

Now the thing that is striking about the German results is this ability to get high temperature metals that are still low in carbon. It is anomalous, so far as our experience in this country goes.

J. T. MacKenzie: Dr. Moldenke, there is a coke in Virginia that I believe Mr. Hansen can take at a one to ten ratio and get 1550 degrees Cent. and yet hold the carbon at 3 per cent. I have no doubt but that a great deal of the differences in temperature that we are talking about come from the character of the coke.

The Influence of Phosphorus on Cast Iron

By J. T. MacKenzie,* Birmingham, Ala.

In a paper[1] presented before this body at its 1925 meeting, the writer advanced the opinion that the high phosphorus bars showed greater deflection per unit of load than the low phosphorus bars. This was shown by the graph of Fig. 8, in the paper mentioned, where the carbon plus one-fourth of the silicon was plotted against the deflection of the standard 2 inch x 1 inch x 24 inch bar at 1,500 pounds load. The statement was made that "the wildest results are for the low phosphorus above the line and for the high phosphorus below the line, indicating that phosphorus actually increases the deflection at a given load."

Purpose of Paper

As the physical aspects of this investigation were treated only incidentally in the above paper, the chief interest being chemical, the writer had not made an exhaustive study of the physical relationships, so the object of the present paper is to present the physical data obtained and especially to discuss this data in the light of the full bending curves rather than their lower portions only, for the 1,500 pound load considered in the previous paper is less than half of the breaking load of some of the bars. In addition to the sets of bars made from the above paper some further sets were made from synthetic electric furnace iron and some results have been included from the principal irons of the Birmingham district, one charcoal iron, one from India, one from Holland, two from Belgium, one from Virginia, and one from Tennessee. Several cupola melts of steel and quite a few pig-steel mixtures have also been included, also one melt of malleable scrap.

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*Chief Chemist, American Cast Iron Pipe Co.

[1] *The Influence of Phosphorus on the Total Carbon Content of Cast Iron*, Trans. American Foundrymen's Association, vol. 33, 1926, pp. 445-467.

Method of Making Bars and Calculating Data

The bars were made in dry sand molds, well blacked, and cast open top, seated on a blacked and dried fire brick. They were broken on a 5,000 pound Riehle autographic transverse machine, carefully calipered *at the point of application of the load,* not at the breaking point, and the load and deflections reduced to standard by the formulas:

$$P = \frac{2P_0}{bt^2}, \quad f = \frac{f_0 bt^3}{2}, \text{ and } d = d_0 t$$

in which P = breaking load in pounds

d = deflection at breaking point, in inches

f = deflection at intermediate point, in inches

b = width of bar } used as pure numbers

t = thickness of bar }

o = observed reading

It should be noted that no bar was accepted which differed from standard by more than 3 per cent in any dimension, so that the largest correction applied was 12½ per cent (the intermediate deflection point for a bar 1.03 inches x 2.06 inches becomes $f = f_0 \times (1.03)^4 = f_0 \times 1.125$) and fully 90 per cent of the bars were within 2 per cent of the standard size in both dimensions.

The analyses were made under the author's direction, using the A. S. T. M. routine methods, except that the sulphur was determined gravimetrically. Silicon and carbon were carefully checked and both are believed to be closer than .05 per cent.

The load values are certainly within 50 pounds, probably 20 pounds, and the deflections are probably correct to .01 of an inch, though in some cases the error may be as great as .02 of an inch due to slight roughness of the bar and some uncertainty as to the exact zero point. The yield of the stirrup which transmits the load on the bar to the weighing system was determined with an Ames dial and found to be .005 of an inch deflection at a load of 2,000 pounds on the bar. As this would be only .0025 of an inch deflection at the middle it is of no moment.

Explanation of Tables and Figures

Table 1: Table 1 shows the complete data used in the discussion. The set number, the raw material used, and the deflections at 1,000, 1,500 and 1,900 pounds, the ultimate load and deflection with the ultimate modulus of elasticity in millions of pounds per square inch $(1728 \frac{P}{D})$, drop test, and brinell hard-

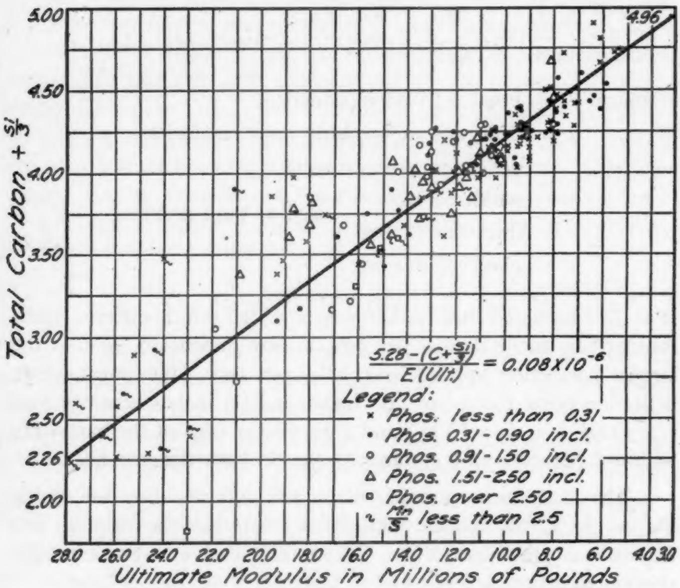

FIG. 1

ness complete the physical data which is followed by the chemical analysis, the quotient $\frac{Mn}{S}$ and the sum $C + \frac{Si}{3}$. The careful reader will find some slight changes in analysis, load, and deflection since previous publications, as a few errors have been discovered and corrected in the present study. This table has been arranged simply in numerical order of the bars as it is of value only to those who really wish to study the data and this arrangement seems to be most useful to the student.

Table 1

Set No.	Material*	Deflection in Inches			Ultimate			Drop Test	Brinell Hardness Number	Chemical Analysis—Per Cents								
		1000 Pounds	1500 Pounds	1900 Pounds	Load Pounds	Deflection In Inches	Elasticity			Si.	S.	Mn.	P.	G.C.	C.C.	T.C.	$\frac{Mn}{S}$	$C+\frac{Si}{3}$
13	S. O. C.	.20	.36	.55	2000	.60	5.8	13.5	157	2.40	.061	.80	.45	3.32	.41	3.73	13.1	4.53
14	Soc and Ingot Mold	.19	.33	.50	2020	.57	6.1	14.0	151	1.82	.069	.72	.36	3.27	.50	3.77	10.4	4.38
17	Woodward 2F	.14	.23	.32	2090	.38	9.5	13.0	207	1.56	.068	.22	.74	2.77	.76	3.53	3.2	4.05
18	Pioneer 3F	.13	.21	.30	2230	.40	9.6	12.0	164	1.73	.081	.38	.78	2.80	.71	3.51	4.7	4.09
29	S. O. C. + Fe P.	.17	.285	.405	2000	.43	8.0	9.0	189	2.16	.078	.62	1.12	2.82	.75	3.57	7.9	4.29
40	Pioneer 2F	.16	.27	.37	2160	.47	7.9	12.5	187	2.01	.061	.56	.80	2.93	.76	3.69	9.2	4.36
41	Debardeleben	.14	.24	.33	2100	.40	9.1	11.5	192	1.50	.054	.41	.91	2.88	.84	3.72	7.6	4.22
42	Sloss Off Grade	.14	.245	.325	2140	.39	9.5	9.0	185	3.18	.061	.32	.84	2.82	.51	3.33	5.2	4.39
46	Sloss No. 1 Soft	.18	.28	.40	2060	.44	8.1	12.0	187	2.91	.042	.84	.77	2.59	.86	3.45	20.0	4.42
49	Ensley Chill Cast	.13	.23	.32	2270	.43	9.1	13.0	194	1.92	.051	.42	.78	3.05	.58	3.63	8.2	4.27
50	Pioneer No. 2 Soft	.13	.22	.29	2090	.34	10.6	10.5	191	2.45	.073	.49	.81	2.80	.61	3.41	6.6	4.23
58	Pioneer No. 2F	.135	.215	.29	2020	.32	10.5	9.5	207	1.87	.074	.48	.80	2.84	.48	3.52	6.5	4.14
63	Woodward Greyforge	.14	.22	....	1700	.26	11.3	8.0	238	1.80	.118	.21	.84	2.02	1.43	3.45	1.8	4.05
76	Pion No. 2F and 5% Steel	.115	.19	.25	2430	.35	12.0	12.5	214	1.89	.072	.51	.82	2.68	.73	3.41	7.1	4.04
78	Pion No. 2F and 10% Steel	.105	.175	.23	2490	.33	13.0	11.0	214	1.89	.083	.44	.80	2.76	.64	3.40	5.3	4.03
79	Pion No. 2F and 15% Steel	.11	.18	.24	2560	.35	12.6	10.0	223	1.91	.082	.46	.96	2.59	.69	3.28	5.6	3.92
80	Pion No. 2F and 20% Steel	.09	.145	.18	3210	.37	15.0	15.5	248	1.68	.109	.41	.89	2.23	.74	2.97	3.8	3.53
82	Pion No. 2F and 25% Steel	.09	.145	.19	3490	.38	15.9	15.0	238	1.65	.095	.38	.66	2.07	.83	2.90	4.0	3.45
83	Pion No. 2F and 30% Steel	.08	.13	.17	2870	.27	18.4	14.5	269	1.19	.090	.35	.67	1.61	1.16	2.77	3.9	3.17
84	Pion No. 2F and 35% Steel	.09	.145	.19	3200	.35	15.8	13.5	248	1.60	.103	.45	.91	2.17	.74	2.91	4.4	3.44
86	Pion No. 2F and 40% Steel	.08	.13	.17	2900	.26	19.3	13.5	302	1.68	.102	.32	.75	1.28	1.26	2.54	3.1	3.10
87	Pion No. 2F and 45% Steel	.09	.15	.19	2830	.30	16.3	11.0	255	1.87	.103	.38	1.07	1.89	.70	2.59	3.7	3.21
88	Pion No. 2F and 50% Steel	.07	.11	.14	2310	.19	21.0	8.5	387	1.96	.102	.35	.98	.14	1.94	2.08	3.4	2.73
89	Pion No. 2F and 55% Steel	.08	.13	.17	3370	.34	17.1	11.5	255	1.58	.085	.39	.99	.166	.97	2.63	4.6	3.16
90	Pion No. 2F and 60% Steel	.065	.11	.14	2780	.21	22.9	11.0	357	1.19	.116	.24	.64	.11	1.94	2.05	2.1	2.45
91	Pion No. 2F and 65% Steel	.07	.105	.14	2950	.21	24.3	10.5	444	1.71	.116	.20	.84	.11	2.24	2.35	1.7	2.92
92	Pion No. 2F and 70% Steel	.07	.105	.14	3070	.22	24.1	....	....	.89	.103	.16	.54	.07	2.65	2.72	1.6	2.32
93	Pion No. 2F and 75% Steel	.075	.11	.14	2680	.18	25.7	10.0	321	1.59	.111	.22	.80	.04	2.09	2.13	2.0	2.66
96	Pion No. 2F and 75% Steel	.07	.12	.15	3150	.25	21.8	10.0	327	2.46	.117	1.24	.97	1.32	.91	2.23	10.6	3.05
100	Pion No. 2F and 75% Steel	.09	.14	.18	3940	.48	14.2	20.0	244	1.53	.119	.93	.24	2.21	.96	3.17	7.8	3.68
105	Sloss No. 2F	.205	.37	....	1790	.49	6.3	10.5	149	1.54	.033	.29	.72	3.33	.62	3.95	8.8	4.46
106	Woodward No. 3F	.17	.29	.42	1930	.43	7.8	10.5	166	1.37	.029	.34	.82	3.15	.62	3.77	11.7	4.23
107	Steel	.10	.16	.21	3200	.46	12.0	17.5	217	2.25	.092	.61	.02	2.55	.82	3.37	6.6	4.12
109	Sloss No. 2 Soft	.20	.355	....	1650	.44	6.5	11.0	166	2.09	.025	.25	.83	3.08	.65	3.73	10.0	4.43
113	Steel	.08	.13	.17	3090	.28	19.1	12.0	241	2.94	.111	1.52	.05	1.65	.83	2.48	13.7	3.46
117	Pioneer No. 2F	.155	.275	.40	2080	.47	7.6	11.0	179	1.92	.060	.53	.82	3.05	.71	3.76	8.8	4.40
118	Pioneer No. 2F	.14	.25	.34	2050	.38	9.3	10.0	187	1.94	.066	.60	.80	2.92	.73	3.65	9.1	4.30

*S. O. C.—Shelby Coke Iron.

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Table 1—Continued

Set No.	Material*	Deflection in Inches: 1000 Pounds	Deflection in Inches: 1500 Pounds	Deflection in Inches: 1900 Pounds	Ultimate: Load Pounds	Ultimate: Deflection In Inches	Ultimate: Elasticity	Drop Test	Brinell Hardness Number	Chemical Analysis—Per Cents: Si.	S.	Mn.	P.	G.C.	C.C.	T.C.	$\frac{Mn}{S}$	$C+\frac{Si}{3}$
124	Steel	.07	.10	.135	4780	.36	22.9	23.0	330	2.02	.228	.94	.09	.18	1.54	1.72	4.1	2.39
125	Steel	.07	.10	.13	5000	.35	24.6	23.0	363	1.76	.184	1.08	.07	.14	1.56	1.70	5.9	2.29
126	S.O.C	.135	.24	.34	2220	.44	9.3	11.0	154	2.19	.082	.64	.42	2.88	.65	3.53	7.8	4.26
127	S.O.C	.14	.26	.36	2060	.43	8.3	12.0	159	2.20	.084	.64	.45	2.99	.52	3.51	7.6	4.24
130	Steel	.10	.155	.20	3320	.43	13.3	16.5	228	1.70	.130	.48	.17	2.48	.80	3.28	3.7	3.85
131	Steel	.075	.13	.17	3660	.34	18.6	14.0	273	1.96	.119	.40	.89	2.10	1.01	3.11	3.4	3.76
137	Malleable	.08	.13	.17	4040	.44	15.9	16.5	238	1.63	.168	.73	.23	1.92	.96	2.88	4.3	3.44
144	Belgian	.135	.215	....	1780	.26	11.8	10.0	226	2.11	.070	.37	1.74	2.59	.71	3.30	5.3	4.00
145	Belgian	.115	.18	.235	2070	.26	13.8	9.0	220	2.03	.080	.30	1.61	2.43	.75	3.18	3.7	3.86
146	Belgian	.13	.205	.28	1950	.29	11.6	9.0	225	2.15	.061	.31	1.67	2.62	.63	3.25	5.1	3.97
153	Woodward Grey forge	.075	.12	....	1540	.12	21.1	8.0	430	.44	.110	.22	.86	.22	3.52	3.74	2.0	3.89
154	T. C. I	.155	.275	....	1830	.38	8.3	11.0	159	1.91	.064	.59	.08	3.04	.82	3.86	9.2	4.50
155	T. C. I	.13	.21	.295	2100	.37	9.8	9.5	183	1.83	.060	.61	.48	2.96	.79	3.75	10.2	4.36
156	T. C. I	.11	.18	.24	2370	.34	12.0	10.5	....	1.70	.070	.57	.89	2.88	.75	3.63	8.1	4.20
157	T. C. I	.12	.18	.24	2190	.29	13.0	9.0	....	1.61	.066	.58	1.27	2.82	.77	3.59	8.8	4.13
158	T. C. I	.105	.16	.205	2620	.33	13.7	9.5	273	1.91	.078	.50	1.69	2.69	.69	3.38	6.4	4.02
159	T. C. I	.155	.27	.40	1960	.43	7.9	11.5	161	1.75	.070	.54	.09	3.00	.80	3.80	7.7	4.38
160	T. C. I	.13	.21	.29	2200	.36	10.5	12.0	207	1.68	.064	.54	.36	2.89	.83	3.72	8.4	4.25
161	T. C. I	.12	.19	.26	2250	.32	12.1	10.0	192	2.12	.077	.52	.72	2.81	.73	3.54	6.7	4.25
162	T. C. I	.11	.17	.215	2330	.28	14.4	9.5	217	2.14	.091	.46	1.28	2.65	.65	3.30	5.1	4.01
163	T. C. I	.15	.25	.355	2140	.45	8.2	12.5	179	1.62	.079	.41	.22	3.18	.79	3.97	5.2	4.51
164	T. C. I	.115	.185	.245	2580	.37	13.0	11.0	225	2.07	.087	.39	1.23	2.85	.71	3.56	4.5	4.25
165	A. E. P	.10	.155	.20	3180	.44	12.5	19.0	244	1.31	.025	.46	.04	2.31	.96	3.27	18.4	3.61
166	A. E. P	.11	.17	.24	2900	.45	11.1	10.0	201	1.32	.039	.46	.04	2.65	.88	3.53	11.8	3.97
167	A. E. P	.09	.14	.175	3300	.34	16.8	15.0	255	1.31	.046	.43	.59	2.16	1.01	3.17	9.3	3.61
168	A. E. P	.09	.13	.17	2900	.24	20.9	12.5	262	1.24	.048	.42	1.55	2.05	.91	2.96	8.8	3.37
169-A	A. E. P	.085	.13	.165	2500	.22	19.6	14.5	248	.94	.072	.29	.07	2.01	1.54	3.55	4.0	3.86
169-B	A. E. P	.105	.16	.21	2600	.35	12.8	12.5	228	1.22	.079	.34	.06	2.43	1.18	3.61	4.3	4.02
169-C	A. E. P	.11	.17	.22	2750	.40	11.9	13.5	207	1.27	.077	.36	.06	2.55	1.04	3.59	4.7	4.01
170	A. E. P	.16	.29	.42	1940	.44	7.6	11.5	164	1.41	.028	.51	.03	3.02	.94	3.96	18.2	4.43
171	A. E. P	.10	.16	.20	2700	.32	14.6	11.0	228	1.29	.054	.54	1.51	2.85	.79	3.64	10.00	4.07
172	A. E. P	.095	.145	.19	2500	.24	18.0	9.0	302	1.52	.074	.44	2.52	2.53	.81	3.34	5.9	3.85
173	A. E. P	.08	.13	.17	2500	.23	18.8	9.0	286	1.41	.059	.46	2.16	2.33	.81	3.14	7.8	3.61
174	A. E. P	.185	.34	.53	1950	.54	6.3	13.0	150	1.30	.042	.36	.08	3.35	.88	4.23	8.6	4.66
175	A. E. P	.15	.25	.365	2250	.51	7.6	13.0	176	1.02	.084	.22	.17	2.98	1.40	4.38	2.6	4.72
176	S. L. S	.155	.27	.40	2100	.50	7.3	13.5	157	.98	.060	.47	.35	3.37	.79	4.16	7.8	4.49
177	S. L. S	.125	.20	.28	2260	.36	10.8	10.0	....	1.06	.070	.53	1.11	3.10	.85	3.95	7.6	4.29

*T. C. I.—Low Phos. Iron; A. E. P.—Anniston Electric Iron; S. L. S.—Shelby Low Silicon Iron; S. O. C.—Shelby Coke Iron.

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Table 1—Continued

Set No.	Material*	Deflection in Inches			Ultimate			Drop Test	Brinell Hardness Number	Chemical Analysis—Per Cents								
		1000 Pounds	1500 Pounds	1900 Pounds	Load Pounds	Deflection In Inches	Elasticity			Si.	S.	Mn.	P.	G.C.	C.C.	T.C.	$\frac{Mn}{S}$	$C+\frac{Si}{3}$
178	S. L. S.	.12	.195	.27	2100	.31	11.7	9.0	228	1.32	.080	.52	1.48	3.14	.66	3.80	6.5	4.24
179	S. L. S.	.105	.165	....	1580	.17	16.1	5.0	277	.90	.146	.46	3.55	2.44	.56	3.00	3.1	3.30
180	S. L. S.	.17	.30	.45	2000	.51	6.8	12.5	163	.90	.078	.38	.39	3.38	.92	4.30	4.9	4.60
181	A. E. P.	.13	.21	.29	2300	.38	10.5	11.0	204	1.22	.071	.35	.69	3.00	.84	3.84	4.7	4.25
182	A. E. P.	.105	.16	.21	2900	.37	13.5	11.5	248	1.17	.061	.34	1.14	2.90	.88	3.78	5.6	4.17
183	A. E. P.	.12	.19	.25	2320	.33	12.1	11.0	217	1.30	.057	.34	1.37	3.05	.71	3.76	6.0	4.19
184	A. E. P.	.10	.145	.18	3470	.24	17.8	10.0	286	1.19	.067	.37	2.25	2.55	.87	3.42	5.5	3.82
185	A. E. P.	.145	.23	.32	2200	.40	9.5	10.5	194	1.11	.088	.22	.13	2.70	1.22	3.92	2.5	4.29
186	S. L. S.	.12	.19	.24	2800	.47	10.3	16.0	209	.92	.080	.34	.35	2.93	.85	3.78	4.2	4.09
187	S. L. S.	.14	.24	.36	2220	.49	7.8	14.5	174	1.54	.072	.43	.35	2.98	.80	3.78	6.0	4.29
188	S. O. C.	.135	.22	.31	2340	.44	9.3	13.5	170	2.33	.087	.61	.42	2.87	.62	3.49	7.0	4.27
190	S. L. S.	.12	.185	.255	2000	.41	10.9	12.5	220	1.05	.103	.33	.36	2.73	1.12	3.85	3.2	4.20
191	S. L. S.	.13	.20	.27	2340	.37	10.9	10.0	214	1.03	.109	.32	1.20	2.91	1.04	3.95	2.9	4.29
192	S. O. C.	.17	.30	....	1800	.39	8.0	9.0	179	2.10	.102	.51	1.53	3.10	.65	3.75	5.0	4.45
193	S. O. C.	.135	.22	.31	2290	.40	9.9	13.5	185	2.09	.101	.51	.46	2.79	.74	3.53	5.0	4.23
194	S. O. C.	.12	.18	.24	2140	.28	13.2	10.5	192	2.10	.163	.56	1.43	2.76	.52	3.28	3.4	3.98
195	S. L. S.	.09	.14	.18	2700	.25	18.7	8.5	269	.84	.133	.42	2.01	2.41	1.09	3.50	3.2	3.78
196	S. O. C.	.125	.20	.27	2130	.33	11.2	9.5	199	1.99	.133	.39	1.51	2.72	.83	3.55	2.9	4.21
197	S. O. C.	.12	.18	.24	2150	.28	13.3	9.5	204	2.04	.141	.36	1.54	2.63	.64	3.27	2.6	3.95
206	Mix Southern	.09	.145	.185	3600	.45	13.8	17.0	228	1.81	.075	.44	.49	2.14	.88	3.02	5.9	3.62
207	Mix Southern	.09	.14	.175	3700	.43	14.9	17.5	225	1.54	.098	.34	.41	1.90	1.02	2.92	3.5	3.43
208	R. H. S.	.12	.185	.24	2600	.35	12.8	11.0	212	4.57	.048	.65	.76	2.40	.35	2.75	13.5	4.27
209	R. H. S.	.15	.25	....	1530	.26	10.2	8.5	202	4.33	.063	.64	2.22	2.43	.21	2.64	10.2	4.08
210	R. H. S.	.24	.44	....	1780	.58	5.3	10.0	127	4.41	.044	.54	.79	3.16	.12	3.28	12.3	4.75
211	R. H. S.	.21	....	....	1820	.28	8.1	8.0	179	4.28	.048	.59	1.76	3.00	.24	3.24	13.3	4.67
216	Mix Southern	.10	.15	.19	3150	.38	14.3	17.0	213	1.38	.111	.36	.75	2.31	1.00	3.31	3.2	3.77
217	R. H. S.	.17	.29	.40	1900	.40	8.2	9.0	159	4.20	.122	.47	.81	2.82	.21	3.03	3.9	4.43
218	R. H. S.	.14	.215	.285	2100	.33	11.0	9.0	214	4.19	.130	.45	1.80	2.53	.19	2.72	3.5	4.12
219	Steel	.065	.10	.125	4300	.28	26.5	16.0	358	1.13	.192	.36	.16	.30	1.72	2.02	1.9	2.40
220	Steel	.065	.095	.125	3250	.21	27.7	14.5	302	.88	.173	.38	.11	.19	1.76	1.95	2.2	2.24
221	Steel	.065	.105	.13	3800	.26	25.2	19.0	375	1.64	.126	.40	.11	.32	2.02	2.34	3.2	2.89
222	Steel	.065	.10	.125	3250	.21	27.7	16.0	366	1.40	.113	.27	.10	.27	1.96	2.23	2.4	2.60
227	Steel	.07	.105	.125	5100	.34	25.9	19.0	364	1.86	.105	1.04	.13	.30	1.66	1.96	9.9	2.58
228	Steel	.065	.10	.12	5100	.34	25.9	21.0	336	1.71	.102	.29	.12	.19	1.51	1.70	2.8	2.27
235	B. M.	.175	.33	....	1760	.42	7.2	11.0	144	1.93	.057	.50	.20	2.97	.81	3.78	8.8	4.42
236	B. M.	.175	.34	....	1790	.44	7.0	11.0	143	2.05	.056	.48	.20	3.05	.69	3.74	8.6	4.42
237	B. M.	.17	.32	....	1700	.39	7.5	11.0	151	1.82	.058	.46	.19	3.00	.73	3.73	7.9	4.34

*S. L. S.—Shelby Low Silicon Iron; S. O. C.—Shelby Coke Iron; R. H. S.—Republic High Silicon Iron; B. M.—Brooke Malleable; A. E. P.—Anniston Electric Iron.

(Continued on page 992)

Table 1—Continued

Set No.	Material*	Deflection in Inches: 1000 Pounds	Deflection in Inches: 1500 Pounds	Deflection in Inches: 1900 Pounds	Ultimate: Load Pounds	Ultimate: Deflection In Inches	Ultimate: Elasticity	Drop Test	Brinell Hardness Number	Si.	S.	Mn.	P.	G.C.	C.C.	T.C.	$\frac{Mn}{S}$	$C+\frac{Si}{3}$
										Chemical Analysis—Per Cents								
238	B. M.	.135	.21	.31	2490	.48	9.0	15.0	170	1.65	.070	.43	.17	2.74	.80	3.54	6.1	4.09
239	B. M.	.12	.20	.29	2560	.49	9.0	15.0	183	1.62	.072	.40	.17	2.78	.73	3.51	5.6	4.07
240	Steel	.105	.17	.23	2600	.36	12.5	17.0	202	1.36	.122	.61	.05	2.81	.94	3.75	5.0	4.20
241	Steel	.08	.13	.16	2490	.23	18.7	14.0	311	.90	.170	.55	.08	2.40	1.28	3.68	3.2	3.98
242	Pioneer No. 2F	.14	.23	.33	2170	.40	9.4	11.5	196	2.03	.114	.51	.85	3.00	.70	3.70	4.5	4.38
243	B. M.	.135	.23	.34	2230	.48	8.0	15.0	163	1.65	.071	.41	.18	2.91	.73	3.64	5.8	4.19
244	B. M.	.16	.31	....	1800	.43	7.2	11.5	148	1.78	.072	.47	.18	2.99	.70	3.69	6.5	4.28
245	B. M.	.135	.23	.31	2060	.35	10.2	11.0	183	1.85	.075	.46	.95	2.81	.67	3.48	6.1	4.10
246	B. M.	.135	.22	.30	2100	.36	10.1	11.0	204	1.68	.094	.45	1.28	2.91	.59	3.50	4.8	4.06
247	B. M.	.135	.22	.30	2000	.32	10.8	10.5	201	1.76	.082	.41	1.30	2.85	.58	3.43	5.0	4.00
248	B. M.	.12	.20	....	1700	.24	12.2	8.0	223	1.60	.108	.40	2.48	2.73	.49	3.22	3.7	3.75
249	B. M.	.12	.20	....	1700	.22	13.4	8.0	228	1.55	.125	.41	2.85	2.67	.55	3.22	3.3	3.73
250	B. M.	.13	.21	.29	1980	.30	11.4	9.5	212	1.68	.096	.43	1.86	2.79	.50	3.29	4.5	3.85
251	B. M.	.13	.21	.30	2320	.41	9.8	15.0	174	1.68	.061	.41	.23	2.87	.70	3.57	6.7	4.13
252	B. M.	.14	.23	.34	2220	.44	8.7	14.0	172	1.76	.064	.40	.23	2.93	.69	3.62	6.2	4.21
253	B. M.	.13	.21	.30	2260	.40	9.8	14.5	174	1.73	.094	.37	.21	2.79	.79	3.58	3.9	4.16
254	B. M.	.15	.26	.39	2070	.45	7.9	13.0	159	1.82	.076	.36	.20	2.92	.71	3.63	4.7	4.24
255	B. M.	.125	.21	.30	2350	.44	9.2	14.0	183	1.70	.096	.32	.21	2.82	.82	3.64	3.3	4.21
256	B. M.	.135	.22	.31	2350	.45	9.0	14.0	171	1.60	.072	.33	.20	2.81	.81	3.62	4.6	4.15
257	B. M.	.115	.19	.26	2320	.36	11.1	15.5	180	1.55	.098	.31	.18	2.75	.82	3.57	3.2	4.09
258	B. M.	.115	.20	.28	2400	.41	10.1	13.5	189	1.57	.100	.31	.19	2.68	.85	3.53	3.1	4.05
259	B. M.	.12	.21	.29	2360	.39	10.5	12.5	194	1.50	.118	.26	.17	2.52	1.12	3.64	2.2	4.14
260	B. M.	.115	.19	.28	2540	.46	9.5	14.5	183	1.53	.110	.33	.17	2.66	.87	3.53	3.0	4.04
261	B. M.	.11	.18	.24	2430	.35	12.0	11.0	201	1.62	.105	.34	.89	2.68	.79	3.47	3.3	4.01
262	B. M.	.12	.19	.26	2290	.34	11.6	10.0	201	1.71	.110	.35	1.03	2.73	.74	3.47	3.2	4.04
263	B. M.	.10	.16	.21	1960	.23	14.7	8.0	238	1.49	.127	.30	2.28	2.40	.82	3.12	2.4	3.62
264	B. M.	.105	.17	.21	2000	.24	14.4	8.0	209	1.50	.129	.30	2.59	2.46	.64	3.10	2.3	3.60
265	B. M.	.105	.165	....	1830	.21	15.1	8.0	246	1.45	.128	.31	2.59	2.36	.70	3.06	2.4	3.54
266	B. M.	.10	.165	....	1800	.20	15.5	8.0	258	1.50	.143	.30	2.45	2.33	.73	3.06	2.1	3.56
267	B. M.	.12	.20	.28	2420	.42	10.0	14.0	189	1.56	.100	.34	.24	2.79	.85	3.64	3.4	4.16
268	B. M.	.13	.22	.31	2420	.44	9.5	14.0	162	1.61	.089	.36	.26	2.83	.79	3.62	4.0	4.16
269	B. M.	.14	....	....	1380	.21	11.8	8.0	236	1.44	.124	.21	2.40	2.58	.85	3.43	1.7	3.91
270	B. M.	.195	....	....	1480	.19	13.5	8.0	241	1.40	.129	.22	2.39	2.42	.83	3.25	1.7	3.72
271	B. M.	.13	.20	....	1500	.20	13.0	8.0	237	1.41	.129	.23	2.33	2.48	.96	3.44	1.8	3.91
289	Steel	.075	....	....	920	.07	23.0	4.0	477	.04	.124	.24	4.80	.06	1.75	1.81	1.9	1.82
297	A. E. P.	.09	.145	.185	2900	.30	16.7	12.0	248	1.29	.049	.38	1.07	2.55	.70	3.25	7.8	3.68
298	A. E. P.	.095	.145	.19	3000	.33	15.7	13.5	245	1.33	.046	.44	.31	2.53	.78	3.31	9.6	3.75

*B. M.—Brooke Malleable; A. E. P.—Anniston Electric Iron.

(Continued on page 993)

Table 1—Concluded

Set No.	Material*	Deflection in Inches: 1000 Pounds	Deflection in Inches: 1500 Pounds	Deflection in Inches: 1900 Pounds	Ultimate: Load Pounds	Ultimate: Deflection In Inches	Ultimate: Elasticity	Drop Test	Brinell Hardness Number	Chemical Analysis—Per Cents: Si.	S.	Mn.	P.	G.C.	C.C.	T.C.	$\frac{Mn}{S}$	$C+\frac{Si}{3}$
299	A. E. P.	.12	.18	.245	2700	.43	10.8	16.0	190	1.37	.040	.39	.14	2.89	.64	3.53	9.7	3.99
301	Steel	.08	.125	.155	3680	.33	19.3	16.5	262	1.89	.107	.29	.05	1.71	1.04	2.75	2.7	3.38
302	A. E. P.	.13	.195	.27	2650	.44	10.4	12.0	181	1.32	.078	.36	.50	2.87	.89	3.76	4.6	4.20
303	A. E. P.	.11	.17	.225	2680	.35	13.2	12.0	222	1.44	.082	.31	.82	2.73	.90	3.63	3.8	4.11
306	A. E. P.	.16	.27	.37	2200	.49	7.8	11.0	170	1.50	.091	.31	.57	3.33	.74	4.07	3.4	4.57
307	A. E. P.	.13	.22	.30	2400	.44	9.4	12.5	181	1.48	.092	.30	.57	3.06	.85	3.91	3.3	4.40
310	Steel	.185	.34	.53	1920	.54	6.1	12.5	146	1.16	.141	.82	.09	3.48	.94	4.42	5.8	4.81
311	Steel	.20	.37	....	1700	.46	6.4	12.0	123	1.70	.125	.66	.10	3.60	.73	4.33	5.3	4.90
312	A. E. P.	.11	.17	.225	2500	.33	13.1	12.0	217	1.36	.048	.42	.79	2.91	.82	3.73	8.8	4.18
313	A. E. P.	.13	.20	.285	2470	.43	9.9	13.0	181	1.37	.045	.42	.38	3.02	.75	3.77	9.3	4.23
314	A. E. P.	.13	.205	.29	2600	.50	9.0	13.5	174	1.41	.035	.42	.14	2.92	.81	3.73	12.0	4.20
315	A. E. P.	.10	.165	.215	2900	.42	11.9	17.0	194	1.37	.029	.43	.04	2.60	.84	3.44	14.8	3.90
318	A. E. P.	.105	.165	.215	2900	.42	11.9	16.0	204	1.33	.030	.33	.05	2.61	.76	3.37	11.0	3.81
319	Burn	.13	.215	.31	2220	.40	9.6	11.5	165	1.82	.052	.82	.28	2.94	.80	3.74	15.8	4.35
320	Burn	.155	.265	.39	2120	.47	7.8	12.5	176	1.70	.047	.58	.30	3.27	.63	3.90	12.3	4.47
321	Dutch	.15	.25	.36	2000	.39	8.9	9.5	183	2.20	.053	.43	.68	2.94	.58	3.52	8.1	4.25
322	Dutch	.145	.245	.34	2110	.39	9.3	9.5	179	2.21	.057	.41	.68	2.92	.63	3.55	7.2	4.29
323	Pulaski	.125	.20	.285	2200	.35	10.9	10.5	187	2.14	.050	.46	.65	2.91	.59	3.50	9.2	4.21
324	Pulaski	.135	.205	.285	2400	.40	10.4	10.5	185	2.16	.049	.47	.65	3.02	.53	3.55	9.6	4.27
336	Steel	.08	.13	.165	3400	.34	17.3	16.5	251	1.95	.189	.38	.08	1.82	1.27	3.09	2.0	3.74
337	Steel	.07	.11	.135	3060	.22	24.0	11.5	402	.80	.192	.26	.12	.35	2.86	3.21	1.4	3.48
339	A. E. P.	.095	.14	.18	2600	.25	18.0	9.0	277	1.26	.020	.38	2.09	2.47	.79	3.26	19.0	3.68
340	A. E. P.	.115	.18	.24	2360	.31	13.1	9.0	228	1.31	.044	.42	1.24	3.18	.42	3.60	9.5	4.04
341	A. E. P.	.12	.195	.26	2500	.38	11.4	10.0	207	1.30	.043	.40	.87	3.06	.69	3.75	9.3	4.18
342	A. E. P.	.10	.15	.20	2900	.34	14.7	11.5	229	1.33	.033	.37	.69	2.64	.82	3.46	11.2	3.90
343	A. E. P.	.125	.21	.30	2500	.46	9.4	13.5	183	1.35	.034	.38	.20	2.92	.80	3.72	11.2	4.17
346	Woodward No. 1 Soft	.17	.30	....	1880	.40	8.1	9.0	....	3.06	.029	.29	.87	2.60	.63	3.23	10.0	4.25
347	Shelby Charcoal	.145	.25	.37	2100	.44	8.2	12.0	159	2.09	.070	.64	.22	2.97	.63	3.60	9.1	4.30
348	Shelby Charcoal	.215	.395	....	1830	.57	5.5	12.0	129	2.29	.045	.63	.25	3.45	.52	3.97	14.0	3.73
349	Shelby Charcoal	.12	.195	.275	2400	.39	10.6	12.0	169	2.02	.042	.68	.22	2.91	.57	3.48	16.2	4.15
351	Shelby Charcoal	.135	.225	.32	2310	.43	9.3	12.0	176	2.12	.053	.63	.24	2.90	.60	3.50	11.9	4.21
353	Roane	.13	.20	.28	2080	.31	11.6	9.5	183	2.19	.053	.33	1.43	2.91	.36	3.27	6.2	4.00
355	Roane	.14	.23	.31	1900	.31	10.6	9.5	202	2.25	.061	.36	1.36	2.78	.57	3.35	5.9	4.10
358	Shelby Char. and 50% Steel	.09	.135	.175	3380	.32	18.2	15.0	262	1.14	.134	.39	.16	1.95	.125	3.20	2.9	3.58
359	Shelby Char. and 25% Steel	.11	.17	.225	2940	.42	12.1	15.0	209	1.68	.096	.53	.18	2.49	.83	3.32	5.5	3.88
360	Shelby Char.	.155	.265	.385	2000	.42	8.2	13.0	161	2.10	.065	.65	.22	3.00	.56	3.56	10.0	4.26
366	Shelby Char. and 10% Steel	.13	.20	.27	2500	.42	10.3	14.5	187	1.60	.092	.46	.28	2.83	.61	3.44	5.0	3.97
374	Mix Southern	.125	.20	.27	2390	.37	11.2	10.0	212	1.58	.080	.30	.77	2.79	.73	3.52	3.7	4.05

*A. E. P.—Anniston Electric Iron.

Figs. 1 and 2: All bars are shown in Fig. 1 and Fig 2. The carbon plus a third of the silicon is plotted against the modulus of elasticity at the breaking point in Fig. 1, and the modulus at 1000 pounds in Fig. 2. The phosphorus is indicated (within

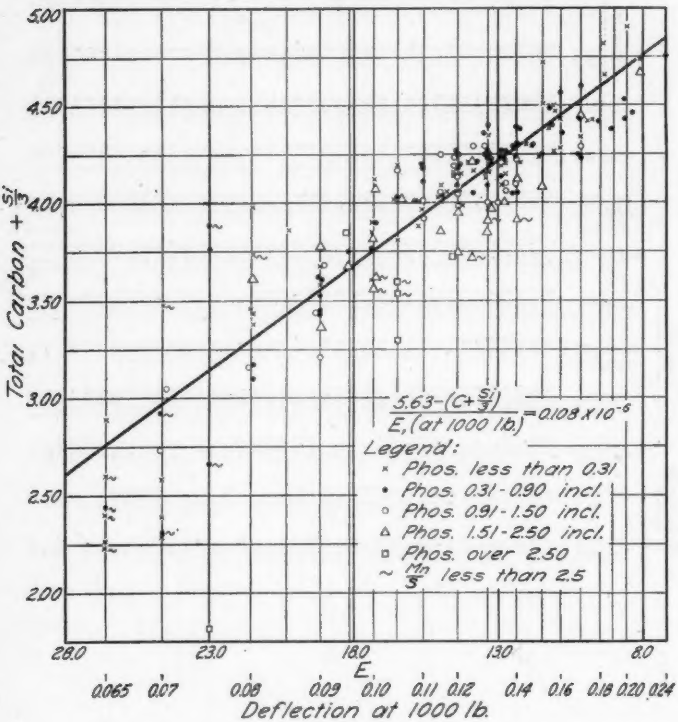

FIG. 2

rather wide limits) by the characters, and the sets are marked which have a manganese-sulphur ratio of less than 2.5. The selection of the split points for the phosphorus are purely arbitrary except that the first point (0.3 per cent P) is about the limit of solid solubility of the phosphide in gray iron as observed by numerous workers.

The value 2.5 for the manganese-sulphur ratio is 50 per cent greater than that called for in manganese-sulfide (1.7). No relation has been established between this ratio and the strength or bending properties of the bars but it is certain that it is of importance, especially just on the border line between white and gray iron. Wüst has shown (Ferrum, XI-4) that manganese is active to about 0.30 or 0.35 per cent but above that it is practically without influence in ordinarily good material. The writer believes that high sulphur or low manganese, and especially both, make the metal more sensitive to variations in melting and casting conditions but that they can both be largely nullified if these conditions are correct. It was shown by the writer[2] that the addition of 0.14 per cent sulphur as brimstone in the ladle did not affect the deflection at 1500 pounds, the strength or the modulus of elasticity, but it is quite certain that a high sulphur, low manganese pig iron made in a blast furnace that is in bad condition will be weak or stiff or both (see Table 1, Set Nos. 63 and 153).

Table 2: In Table 2 is shown a summary of the results as marked on the two graphs. An inspection of the two figures shows that there is a marked shifting of the relative positions of the very low phosphorus irons (x) above the line in Fig. 2 to below the line in Fig. 1 and an even greater shifting of the high phosphorus irons (Δ) in the opposite direction. Table 2 is made by counting the bars of each group above, below and between two lines .05 per cent on each side of the calculated line for carbon plus one-third of the silicon for each figure. These lines (not shown) will probably represent the maximum error in analysis and physical data. Considering only the bars below this band (which position means that they bend more than their carbon and silicon call for) we have proceeding uniformly from Fig. 2 (1000) to Fig. 1 (ult) the result shown in Table 3. Table 2 also shows the average phosphorus, carbon $+\frac{\mathrm{Si}}{3}$, strength, drop test and brinell hardness of each group, and while the writer realizes the danger of using average values in a case of this kind, they seem to point to certain conclusions which were reached

[2] J. T. MacKenzie, Transactions A. S. T. M., 1924.

independently by a study of the individual bending curves. Group II, Tables 2 and 3, unfortunately has considerably higher carbon $+\frac{\text{Si}}{3}$ than the others and therefore cannot be directly compared, but groups I, II, and IV are almost identical in this factor and

Table 2

SUMMARY OF FIGS. 1 AND 2.

			Fig. 1	Fig. 2
Group I—66 sets		Above*	27.3%	39.4%
	(Phos. 0.15%; C + $\frac{\text{Si}}{3}$, 3.93%).	Between*	19.7%	31.8%
	(Load 2,710 lbs.; Drop 14.4 in	Below*	53.0%	28.8%
	(Brinell Hardness No. 211)			
Group II—66 sets		Above*	36.9%	40.0%
	(Phos. 0.67%; C + $\frac{\text{Si}}{3}$, 4.05%)	Between*	29.2%	24.6%
	(Load 2,415 lbs.; Drop 11.0 in.)	Below*	33.9%	35.4%
	(Brinell Hardness No. 210)			
Group III—25 sets		Above*	48.0%	40.0%
	(Phos. 1.16%; C + $\frac{\text{Si}}{3}$, 3.90%)	Between*	16.0%	16.0%
	(Load 2,415 lbs.; Drop 11.0 in.)	Below*	36.0%	44.0%
	(Brinell Hardness No. 231)			
Group IV—23 sets		Above*	47.8%	26.1%
	(Phos. 1.95%; C + $\frac{\text{Si}}{3}$, 3.91%)	Between*	26.1%	4.3%
	(Load 1,950 lbs.; Drop 9.0 in.)	Below*	26.1%	69.6%
	(Brinell Hardness No. 234)			
Group V—6 sets		Above*	16.7%	16.7%
	(Phos. 3.15%; C + $\frac{\text{Si}}{3}$, 3.31%)	Between*	16.7%	0.0%
	(Load 1,755 lbs.; Drop 7.0 in.)	Below*	66.6%	83.3%
	(Brinell Hardness No. 290)			

*Refers to position with respect to lines .05% on each side of the lines shown in Figs. 1 and 2.

Table 3

CHANGE IN RELATION FROM 1,000 POUNDS TO BREAKING POINT

Group*	I.	.00— .30	P	increases	24.2%	from	28.8%	to	53.0%
Group	II.	.31— .90	P	decreases	1.5%	from	35.4%	to	33.9%
Group	III.	.91—1.50	P	decreases	8.0%	from	44.0%	to	36.0%
Group	IV.	1.51—2.50	P	decreases	43.5%	from	69.6%	to	26.1%
Group	V.	2.51—4.80	P	decreases	16.7%	from	83.3%	to	66.6%

*From Fig. 2.

can safely be contrasted on phosphorus alone. The strength and drop test on three groups fall consistently as the phosphorus increases.

Fig. 3: As is shown in Fig. 3 if groups II and V are roughly recalculated to the same $C + \frac{Si}{3}$ as the others, the strength line takes the slope $W = 2880 - 490P$, or roughly speaking, the strength line of this bar drops 500 pounds for each per cent increase in phosphorus. The drop test also falls rapidly and the brinell shows a slow and rather uncertain rise though Group V is too low in carbon $+ \frac{Si}{3}$ to be useful in comparison.

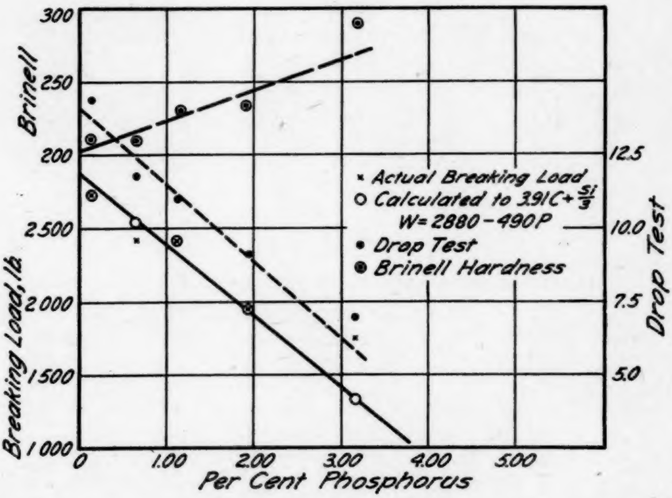

FIG. 3—INFLUENCE OF PHOSPHORUS WITHOUT REGARD TO ORIGIN

A critical examination was made of Groups IV and V as to which bars were above and which bars below the line and it was found that all of the bars of these two groups above the line in Fig. 2 were very much stronger than the average, the six bars of Group IV above the line giving the data of Table 4. And the average of the sixteen below the line is:

$$\text{Strength, } 1700; \quad C + \frac{Si}{3}, \quad 3.90; \quad P, \ 1.98$$

In Group V the only bar above the line in Fig. 2 is No. 172, AEP, which had a strength of 2500 pounds, $C+\frac{Si}{3}$ of 3.85 and phosphorus 2.52, the other five bars of the group averaging 1600 pounds breaking load, 3.20 per cent $C+\frac{Si}{3}$, and 3.28 per cent P. No. 172 seems to belong to Group IV rather than Group V. This leads to the conclusion that the phosphorus, while actually stiffening gray iron, cuts off the lower portion of the bending curve and therefore the actual bending of a high phosphorus bar

Table 4

BARS OF GROUP IV ABOVE THE LINE IN FIG. 2

Set No.		Strength pounds	$C+\frac{Si}{3}$	Phosphorus per cent
173	AEP	2,500	3.61	2.16
195	SLS	2,700	3.78	2.01
171	AEP	2,700	4.07	1.51
184	AEP	2,470	3.82	2.25
158	TCI	2,620	4.02	1.69
196	SOC	2,130	4.21	1.51
	Average	2,520	3.92	1.86

Table 5

TRIANGULAR RESILIENCE OF PHOSPHORUS GROUPS OF FIG. 4

Group	Set No.	Phosphorus per cent	$C+\frac{Si}{3}$ per cent	Resilience
a	144	1.74	4.00	232
a	353, 355	1.40	4.05	309
a	17, 18, 58	0.77	4.09	388
b	321, 323	0.67	4.23	388
b	41, 50, 106	0.85	4.23	397
c	323, 324	0.67	4.28	446
c	49, 118, 346	0.82	4.34	418
d	319	0.28	4.35	444
d	40, 118, 242	0.82	4.34	444
e	154	0.08	4.50	346
e	235, 236	0.20	4.42	384
e	320	0.30	4.47	498
e	105	0.72	4.46	438
e	117	0.72	4.40	489

at a low load is greater than that of a similar low phosphorus bar. Where other influences counteract the weakening tendency of the phosphorus, the high phosphorus bars are stiffer throughout.

It is noteworthy that the only irons capable of retaining high strength with high phosphorus were the two low blast irons (Shelby) and the two made from steel scrap—the T. C. I. pig made in a blast furnace and the Anniston pig made in a basic

electric furnace. This leads to the suggestion that much of the superior strength and impact value of Group I is due to the large percentages of steel used in some stage of their production

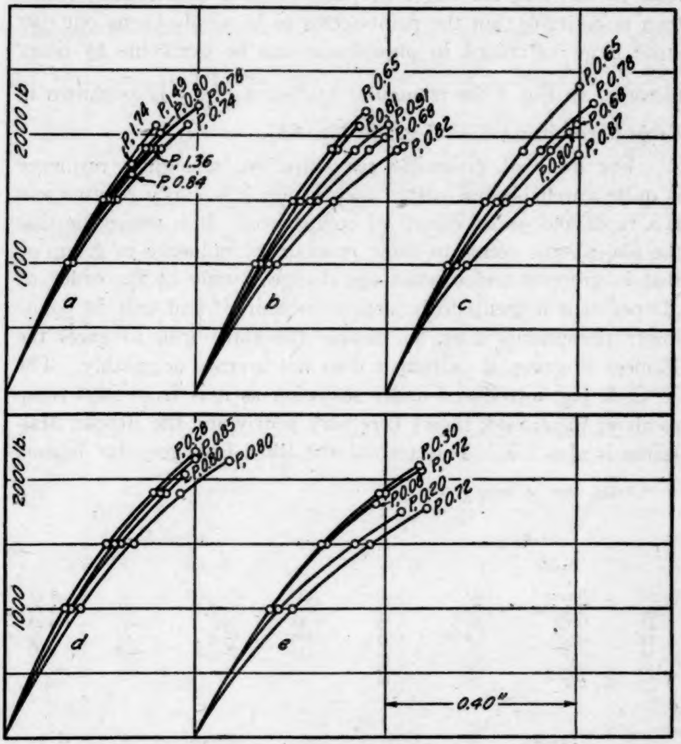

FIG. 4—BREAKING CURVES FOR COKE IRONS FROM ORE IN HOT BLAST FURNACES

and to the further thought that the influence of the phosphorus is thus overdrawn in Fig. 3.

Fig. 4: With the thought of the preceding sentence in mind Fig. 4 was drawn showing the load deflection curves for hot blast

coke irons[3] made from ores. The irons are grouped as closely as possible by their carbon silicon content $(C + \frac{Si}{3})$. The selection is very much limited by the effect of phosphorus on the total carbon and the range of phosphorus is considerably lower than is desirable, but the point seems to be amply borne out that quite large variations in phosphorus can be overcome by other factors. In Fig. 4 the triangular resilience $(\frac{Pd}{2})$ is as shown in Table 5 (omitting the off-grade No. 63).

For irons of dissimilar curvature this triangular resilience is quite unreliable but within each group it is fairly relative and is a rapid and useful means of comparison. It is noticeable that the phosphorus seems to show pronounced influence in group *a*; that in group *b* and *c* when the change is only of the order of .25 per cent it seems to be entirely obscured; and that 54 points lower phosphorus does not enable the Burn iron to excel the Pioneer in group *d*. Group *e* does not average acceptably. The T. C. I. pig, introduced under suspicion as it is from steel scrap as above mentioned, shows here very poorly and the Brooke Malleable is also low. This test of the Burn iron goes far beyond

[3] Note: Data of Irons of Fig. 4.

Group a

	Brand	P	$C + \frac{Si}{3}$
353	Roane	1.43	4.00
144	Belgian	1.74	4.00
63	WGf	.84	4.05
17	W_2F	.74	4.05
18	P_3F	.78	4.09
355	Roane	1.36	4.10
58	P_2F	.80	4.14

Group b

	Brand	P	$C + \frac{Si}{3}$
323	Pulaski	.65	4.21
41	DeB_3F	.91	4.22
50	P_2F	.81	4.23
106	W_3F	.82	4.23
321	Dutch	.68	4.25

Group c

	Brand	P	$C + \frac{Si}{3}$
346	Wis	.87	4.25
49	Ensley	.78	4.27
324	Pulaski	.65	4.27
322	Dutch	.68	4.29
118	P_2F	.80	4.30

Group d

	Brand	P	$C + \frac{Si}{3}$
118	P_2F	.80	4.30
319	Burn	.28	4.35
40	P_2F	.80	4.36
242	P_2F	.85	4.36

Group e

	Brand	P	$C + \frac{Si}{3}$
117	P_2F	.72	4.40
235–6	BM	.20	4.42
105	S_2F	.72	4.46
320	Burn	.30	4.47
154	T. C. I.	.08	4.50

the one in group *d,* but still the Pioneer is very close to it and the Sloss with poor strength holds third place with a remarkable deflection.

Fig. 5: To eliminate as far as possible the numerous vari-

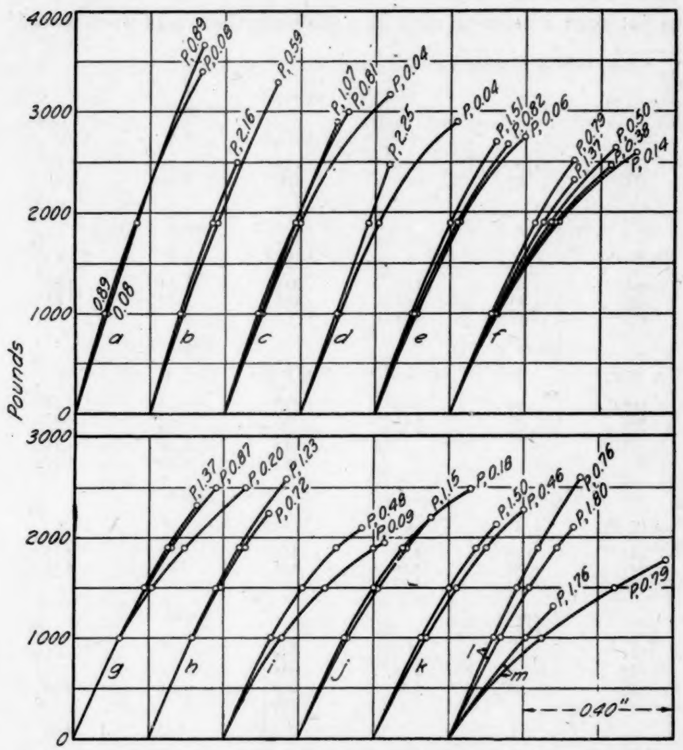

FIG. 5—INFLUENCE OF PHOSPHORUS ON BENDING CURVES OF IRON OF SAME ANALYSIS AND IDENTICAL ORIGIN

ables present in so many kinds of irons, another selection was made using only one base material for each group and selecting the sets with the closest possible silicon content and carbon content so that any combination of these two elements would be prac-

tically the same. These curves[4] are plotted in Fig. 5 and though there are some few exceptions the conclusions drawn from the whole mass of tests as to the stiffening effect of phosphorus are well sustained, but the general averages for strength shown in Table 2 and Fig. 3 do not seem to hold good. As it is impossible to put such a mass of data on a diagram these sets were placed

[4] Note Data of Irons of Fig. 5.

Group a

Steel	P	$C + \frac{Si}{3}$
336	.08	3.74
131	.89	3.76

Group b

A. E. P.	P	$C + \frac{Si}{3}$
167	.59	3.58
173	2.16	3.61

Group c

A. E. P.	P	$C + \frac{Si}{3}$
165	.04	3.60
298	.81	3.62
297	1.07	3.55

Group d

A. E. P.	P	$C + \frac{Si}{3}$
315	.04	3.90
184	2.25	3.82

Group e

A. E. P.	P	$C + \frac{Si}{3}$
169-C	.06	4.02
303	.82	4.07
171	1.51	4.09

Group f

A. E. P.	P	$C + \frac{Si}{3}$
314	.14	4.20
313	.38	4.23
302	.50	4.20
312	.79	4.19
183	1.37	4.19

Group g

A. E. P.	P	$C + \frac{Si}{3}$
343	.20	4.17
341	.87	4.18
183	1.37	4.19

Group h

T. C. I.	P	$C + \frac{Si}{3}$
161	.72	4.25
164	1.23	4.25

Group i

T. C. I.	P	$C + \frac{Si}{3}$
159	.09	4.38
155	.48	4.36

Group j

B M	P	$C + \frac{Si}{3}$
238, 239, 258, 260	.18	4.03
246, 262	1.15	4.05

Group k

SoC	P	$C + \frac{Si}{3}$
193	.46	4.23
196	1.50	4.21

Group l

R H S	P	$C + \frac{Si}{3}$
208	.76	4.27
218	1.80	4.12

Group m

R H S	P	$C + \frac{Si}{3}$
210	.79	4.75
211	1.76	4.67

in Table 6 which shows the phosphorus, breaking load and deflection, triangular resilience, drop, and brinell for each set arranged in the same groups shown in Fig. 5. Even a casual perusal of this table shows the value of the resilience calculation and of the drop test and how little dependence can be placed on

Table 6

PHYSICAL DATA ON BARS SHOWN IN FIG. 5

Group	Set No.	Phosphorus per cent	Breaking Load pounds	Breaking Deflection inches	Resilience	Drop	Brinell Hardness No.
a	336	0.08	3,400	.34	578	16.5	251
a	131	0.89	3,660	.34	622	14.0	273
b	167	0.59	3,300	.34	561	15.0	255
b	173	2.16	2,500	.33	413	9.0	286
c	165	0.04	3,180	.44	700	19.0	244
c	298	0.81	3,000	.33	495	13.5	245
c	297	1.07	2,900	.30	435	12.0	248
d	315	0.04	2,900	.42	609	17.0	194
d	184	2.25	2,470	.24	296	10.0	286
e	169*c*	0.06	2,750	.40	550	13.5	207
e	303	0.82	2,680	.35	469	12.0	222
e	171	1.51	2,700	.32	432	11.0	228
f	314	0.14	2,600	.50	650	13.5	174
f	313	0.38	2,470	.43	531	13.0	181
f	302	0.50	2,650	.44	583	12.0	181
f	312	0.79	2,500	.33	413	12.0	217
f	183	1.37	2,320	.33	383	11.0	217
g	343	0.20	2,500	.46	575	13.5	183
g	341	0.87	2,500	.38	475	10.0	207
g	183	1.37	2,320	.33	383	11.0	217
h	161	0.72	2,250	.32	360	10.0	192
h	164	1.23	2,580	.37	477	11.0	225
i	159	0.09	1,960	.43	421	11.5	161
i	155	0.48	2,100	.37	388	9.5	183
j	238, 239	0.18	2,500	.46	575	14.5	181
j	258, 260, 246, 262	1.15	2,200	.35	385	10.5	203
k	193	0.46	2,290	.40	458	13.5	185
k	196	1.51	2,130	.33	351	9.5	199
l	208	0.76	2,600	.35	455	11.0	212
l	218	1.80	2,100	.33	346	9.0	214
m	210	0.79	1,780	.58	516	10.0	127
m	211	1.76	1,320	.28	185	8.0	179

strength alone in cast iron. In all but three groups (*a, f,* and *h*) the resilience and drop fall steadily while the brinell rises. In group *a,* the drop test shows that the transverse test on No. 336 was vitiated in some way and a reference to the original notes shows small flaws in the transverse test but not in the drop. In group *f,* only one set is out of line on the resilience and its drop test is in place. No reason can be found for the inversion of

both tests in group *h* but the brinell runs true to form as it does in every group without exception as to direction of the line, though the slope is not so dependable Again resorting to averages and excluding groups *a* and *h* as being the exceptions which prove the rule, we find that the average change per 1 per cent increase in phosphorus is for strength, a drop of 196 pounds; for resilience, a drop of 197 pounds, for impact, a drop of 3.5 inches; and for brinell, an increase of 27 numbers.

Fig. 6: Fig. 6 shows a similar selection from the crucible melts[5] made by Wüst (Ferrum XII-7), a set of bars made by Coe, and a set made by Adamson as reported by Coe[6]. The curves as drawn in are purely hypothetical, as their published data give nothing but the ultimate values. Wüst's data contains brinell hardness, impact test, and a full resilience value ob-

[5] Note: Data of Irons of Fig. 6.

Group A—Adamson

No.	P	$C + \frac{Si}{3}$
1	.30	3.60
2	.69	3.70
3	1.08	3.63

Group B—Wüst

No.		P	$C + \frac{Si}{3}$
2	Reihe I	.25	3.59
5		.55	3.61
11		1.65	3.60
4	Reihe II	.41	3.60
9		1.13	3.60
10		1.55	3.59

Group C—Wüst

No.		P	$C + \frac{Si}{3}$
1	Reihe I	.16	3.71
3		.30	3.69
7	Reihe II	.88	3.66
12		1.86	3.70
13		1.98	3.69

Group D—Wüst

No.		P	$C + \frac{Si}{3}$
1	Reihe III	.04	4.04
3		.20	3.98
5		.35	3.99
6		.60	3.98
8		.90	4.02
12		1.61	4.04

Group E—Wüst

No.		P	$C + \frac{Si}{3}$
1	Reihe IV	.03	3.93
2		.06	3.88
6		.28	3.80
7		.33	3.87
10		.99	3.92

Group F—Wüst

No.		P	$C + \frac{Si}{3}$
6	Reihe VI	.38	3.84
11		.89	3.82

Group G—Coe

No.	P	$C + \frac{Si}{3}$
2	.25	4.31
3	.45	4.25
5	.84	4.31
6	1.07	4.33

[6] Staffordshire Iron and Steel Institute, Jan., 1914.

tained by integrating the actual curves by means of a planimeter which is far superior to the inexact resilience value used by the author. No such values are available for the work of Coe and Adamson.

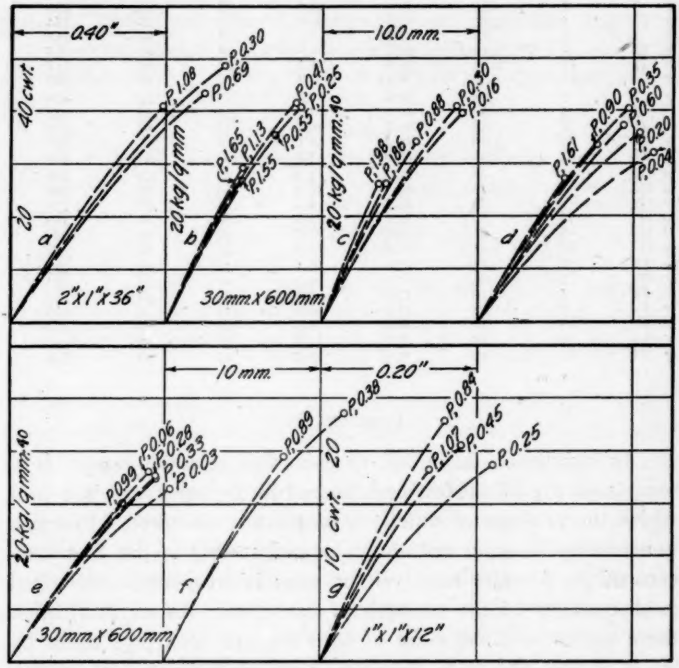

FIG. 6—INFLUENCE OF PHOSPHORUS ON BENDING CURVES AS DETERMINED BY WÜST, ADAMSON AND COE

Table 7: Table 7 contains the data on Wüst's sets shown in Fig. 6, groups *b* to *f*. The units are different from those used by the writer but the excellent correlation shown between resilience and drop test is again very evident and appears to be of the same order. The increase of brinell hardness is also quite similar.

Table 7

Group	Set No.	Phosphorus per cent	Breaking Load Kilograms per Square Millimeters	Breaking Deflection Millimeters	Resilience	Drop	Brinell Hardness No.
b I	2	.25	40.7	8.6	.52	.70	235
b II	4	.41	41.6	8.4	.57	.55	246
b I	5	.55	35.6	7.1	.36	.49	248
b II	9	1.13	29.3	4.9	.24	.45	283
b II	10	1.55	26.5	4.5	.21	.44	287
b I	11	1.65	26.6	4.8	.17	.43	299
c I	1	.16	39.6	9.0	.47	.72	234
c I	3	.30	40.9	8.7	.56	.62	230
c II	7	.88	34.2	6.0	.32	.47	271
c II	12	1.86	26.2	4.1	.19	...	299
c II	13	1.98	26.0	3.6	.17	.42	301
d III	1	.04	32.0	11.3	.50	...	181
d III	3	.20	35.9	10.4	.59	.62	198
d III	5	.35	40.5	9.7	.66	.59	218
d III	6	.60	37.1	9.4	.56	.59	226
d III	8	.90	33.6	7.7	.42	.49	240
d III	12	1.61	27.3	5.7	.23	.42	252
e IV	1	.03	33.0	10.4	.45	.68	222
e IV	2	.06	36.1	9.0	.47	.56	221
e IV	6	.28	35.4	9.5	.51	.51	221
e IV	7	.33	35.0	9.5	.48	.51	219
e IV	10	.99	30.2	7.4	.34	.40	238
f VI	6	.38	47.2	11.5	.82	.76	207
f VI	11	.89	38.5	7.6	.49	.54	225

Conclusions

In conclusion it is well to point out that the results here considered are all on test bars poured in dry sand with hot iron where the problem of fluidity is practically obscured. It seems unnecessary to point out that a sound casting is the first concern of the foundry man, yet the point is frequently overlooked in discussions of the strength of cast iron. As an illustration there comes to hand a set of tests on cast iron pipe made by A. N. Talbot and F. E. Richart (Transactions A.S.T.M. 1926). Four lots were selected from their paper of approximately the same analysis, all made by the common method with dry sand molds and cores cast vertically in twelve foot lengths. The analysis and results are shown in Table 8. The tests are described in detail in the original paper except the drop with three inch increments which was made at two feet from either end as well as at the middle. These tests have been made since the paper was written and were kindly placed at the author's disposal by Prof. Talbot.

It is quite evident that the drop test in the middle of the pipe shows a great superiority for lot 40 (the low phosphorus) and the average for the other drop test is distinctly higher for this lot, but it barely excels lot 73 on the minimum. Lot 4 was unfortunately exhausted before these tests were made. In the bursting test lot 40 is distinctly inferior to the other three of much higher phosphorus, especially on minimum value. In resilience (flexure test) lot 40 shows better than 70 or 73, but quite below lot 4. The greater fluidity of the higher phosphorus

Table 8

DATA OF CAST IRON PIPE (TALBOT AND RICHART)

Lot No.	Total Carbon	Silicon	Sulphur	Manganese	$\frac{Mn}{S}$	$C + \frac{Si}{3}$	Phosphorus	Tensile Strength Bursting Test			Flexure Test			Drop Test 3" Increment			
								Max.	Min.	Avg.	Modulus of Rupture	Modulus of Elasticity	Resilience	Average 6" Increment	Max.	Min.	Av.
4	3.56	1.40	.07	.34	5	4.03	.77	18.6	13.6	16.1	32.2	9.4	11.2	16.6			
40	3.50	1.65	.08	.50	6	4.05	.49	16.6	11.5	13.4	29.3	10.2	8.4	20.3	13.2	8.4	10.6
70	3.56	1.44	.05	.38	8	4.04	.88	15.7	14.2	14.8	28.4	10.1	8.0	14.4	11.2	6.7	8.6
73	3.51	1.60	.06	.35	6	4.04	.86	18.1	14.6	16.4	26.8	10.9	7.1	14.2	9.3	8.2	8.8

irons immediately offers as the explanation, for this type of casting is peculiarly sensitive to the casting properties of the metal.

It will undoubtedly be found true that for each type of casting the maximum strength will be found at the lowest phosphorus compatible with fluidity. For castings where resistance to shock is of importance, low phosphorus irons should be used and the necessary fluidity obtained by raising the carbon, but ordinarily no trouble will be experienced with phosphorus running to 0.8 per cent if carbon and silicon are correctly proportioned to give the strength desired.

Discussion

J. W. Bolton: The question of this paper was brought up last year about the practical effect of the change of phosphorus upon the deflection of cast iron. Mr. MacKenzie's paper, which was presented last year, gave a number of results which indicated that at 1500 pounds load the percentage of phosphorus did not lower, in fact, it seemed to increase the deflection of cast iron. At that time, having done some work along that same line, we disagreed with him and furnished results tending to show that at the breaking load, other elements being the same, the phosphorus

decreased deflection. As I understand Mr. MacKenzie's presentation of this paper today, he shows that when he went to the ultimate load rather than to 1500 pounds, he substantiated that contention. Is that correct, Mr. MacKenzie?

J. T. MacKenzie: Yes.

R. S. MacPherran: I might say that Mr. MacKenzie's findings practically confirm our machine shop experience, that when you reduce the phosphorus, you can also reduce the silicon and keep the same degree of machinability, because you thereby naturally decrease the hardness.

J. T. MacKenzie: There was a striking point brought out in this investigation on cast iron pipe, that one set of pipe which were made with phosphorus of only 0.50 per cent did not develop as high a bursting strength as the higher phosphorus pipe, but still the drop test made on the middle of the pipe was quite superior. In examining the results we found that the phosphorus of .70 to .80 per cent seemed to enable the iron to make the castings sound throughout, whereas with phosphorus of .50 there were flaws in the lower part of the casting.

Now, when we subjected the pipe to hydraulic pressure, the hydraulic pressure immediately found the weak place, whereas with the drop test we were up in the middle of the casting, which is, of course, poured on end, and it was perfectly sound. So we got the benefit of the low phosphorus iron in the upper half or, say, two-thirds of the pipe, but the effective strength was better for the higher phosphorus iron. I wouldn't begin to apply that to phosphorus above that range, because that is the only range we have. But I do know the French make a very excellent cast iron pipe with phosphorus as high as 1.70 per cent. I think that is the answer, that the phosphorus gives the necessary fluidity to make a perfectly sound casting, and, after all, that is the first thing we have to strive for. It doesn't make any difference how strong we can make a test bar; if the casting is not sound throughout, we would have been better off with a little less strength in the bar.

O. Smalley: There is one point I take exception to in Mr. MacKenzie's paper and that is, he leads us to believe that up to .8 per cent phosphorus is not detrimental either to the strength or to the solidity of the casting. It is my experience that between .25 and .8 per cent of phosphorus is a very delicate and dangerous region of phosphorus in producing differential freezing, and where there is a change of section and the formation of phosphides is thrown out, it tends to cause porosity and spongy places. Under .25 you eliminate that simply because you reduce the extension of the freezing range. When you increase that quantity to .8, you get a free flow of the phosphide, which feeds into these places. But there is plenty of evidence to show that possibly the most important point of phosphorus is either the elimination or the production of spongy castings. I would like Mr. MacKenzie's view on that.

J. W. Bolton: During the last several years we have all come to have a more accurate view of the true nature of phosphorus as it occurs in commercial cast irons. Very fortunately and very interestingly, this has been indicated in an indirect manner, both in the paper by Mr. Smalley and in that by Mr. MacKenzie. There are two angles to these practical findings. One of them is the nature of the phosphorus formations and the reasons whereof, and secondly, the constitution of the phosphorus formation in regard to the amount of carbon it contains. That second point I am going to ask Mr. MacKenzie to explain to you, and I would like to explain this first point to you.

It has been assumed for many years among gray iron metallurgists that phosphorus in commercial cast iron occurred as steadite, a eutectic alloy containing, roughly, about 10.8 per cent of phosphorus and 89.2 per cent of iron—I am speaking of gray iron alloy. This contention was based on the very excellent work of the late Dr. Stead of England. Dr. Stead's work was all right, but the application of it to gray iron has not been right. Dr. Stead found this eutectic alloy at 10.2 per cent phosphorus. However, to review very briefly his work, he found that if you start out with pure iron-phosphorus alloys, in the lower contents of phosphorus, you found a solid solution. There is no direct evidence of structural evidence outside of a little difference in grain growth, of the presence of phosphorus in the alloy.

As you increased that range of phosphorus to 1.7 per cent, you found a new structural component appeared which was cellular, or what we known as a honeycombed structure. His iron structure was a perfectly clear network structure and you got evidence, over 1.7 phosphorus, of a cellular structure. Proceeding beyond that, you got increasing amounts of that cellular structure until at 10.2 per cent you got 100 per cent of the honeycombed form.

Now, cast iron metallurgists, for some inexplicable reason, assumed that this eutectic form was the only one occurring in cast iron. That isn't so. You have in the lower phosphorus cast irons, just as Mr. Smalley says, a solid solution steadite. It is not a eutectic alloy in any sense of the word. It can be easily shown microscopically, it can be shown from Wüst's work in Germany, it can be shown in deflection values. It is not until you get up around half a per cent of phosphorus in ordinary cast irons that are fairly high in pearlite that you get the eutectic alloy. Therefore, you not only have a smaller amount of this material (I am not going to call it low phosphorus steadite and low phosphorus irons), but you have an entirely different component. Therefore, between, say, .25 and .50 per cent phosphorus, as Mr. MacPherran has noted, there is a difference in machinability, not only because of the amount, but because of a difference in the properties of the alloy.

E. V. Ronceray: Our experience in France in the tests that have been made is that the strength of the cast iron in the tensile and bending tests is very much modified by the presence of phosphorus, we find they

are much more frail, they break under the drop test more easily. We find that consistently. You can see the reason why Mr. Portevin wanted to get out of the drop test. The drop test that we have is not satisfactory, because the figures we find in testing are subject to experimental error; because the test is not so good, we have to chance it.

J. T. MacKenzie: The point Mr. Smalley raised about the shrinkage I am afraid I will have to pass up. We have no castings where we encounter that difficulty, for our range of castings is rather limited.

About the drop test, I think one of the very gratifying results of this work is the value of the resilience calculation in estimating the impact value of the casting. You will notice that the resilience calculations follow the drop test almost invariably. There are a few exceptions. Group (a) Table 6 was an exception. But the resilience, for instance, in group (b) dropped from 561 to 431, the drop test fell from 15 inches to 9. In group (c) the resilience drops 700, 495, 435, and the drop test shows 19, 13.5 and 12, close to paralleling results.

Table 7 is taken from Wüst, and he used the planimetric resilience, which is accurate. The triangular resilience, which I used, is, of course, inaccurate and is only comparable with irons of the same curvature. But Wüst's results are exact.

If you will follow group (b), the resilience drops, it doesn't drop straight, but it drops, .52, .57, .36, .24, .21, .17, following a phosphorus increase from .25 to 1.65. The drop test falls, .70, .55, .49, .44. .43. This group (f), the resilience drops from .82 to .49, and the drop test falls from .76 to .54. So that while I don't say we need to quite abandon the drop tests, I think the impact resistance of cast iron can be very well obtained from the ordinary transverse test by multiplying the breaking load by the deflection.

R. F. Harrington: I would like to ask Mr. MacPherran if he has any idea as to the difference in machinability or difference in Brinell, possibly, between an iron of .40 and .50; in other words, right in this range of phosphorus that has been discussed.

R. S. MacPherran: We haven't cut as close as that. We made a decided change, from about .70 or .75 phosphorus down to about .20 phosphorus. Of course, that is an awfully long jump to make in one change. We found we could run the silicon quite a bit lower and still keep the same degree of machinability. The steadite seems to occur in hard spots. The idea was, it occurred in hard globules, spots, and it was hard on the tool.

R. F. Harrington: It seems there have been some indications that between .40 and .50 there is really a greater difference in hardness, or Brinell, than will be indicated by Mr. MacKenzie's paper, which shows 27 points drop for a per cent difference in phosphorus. That is the reason for my question.

J. T. MacKenzie: We don't machine.

Melting All Steel Charges in a Cupola Furnace

By T. F. Jennings,* Garfield, Utah

Steel scrap has been incorporated in gray iron mixtures and in that form has been melted in cupola furnaces for many years. The practice is not universal and amateurs almost invariably come to grief in early trials, but a knowledge of how it is done is fairly common among experienced foundrymen. Metal produced by melting a mixture of gray iron, pig or scrap and steel in varying proportions is known commercially as semi-steel to distinguish it from straight mixtures of gray iron, malleable iron or steel. Also the term is applied almost exclusively to cupola melted metal.

The term semi-steel is rather indefinite since it is applied indiscriminately to any mixture of gray iron containing an addition of steel. For that reason it is viewed somewhat askance by scientists who insist on material conforming to strict formulas, specifications and analyses. Also, since the carbon content of semi-steel places it in the gray iron rather than in the steel classification, they claim that the term semi-steel is a misnomer. This paper does not propose to discuss this controversial point. For all practical purposes semi-steel has been accepted as a proper term and no doubt it will remain in foundry nomenclature until, if ever, a more appropriate term is coined.

Development of this material has been gradual over a long period of years and represents the pioneering efforts of a great number of foundrymen. It was not *discovered* by any one person in particular although several prominent men carried their investigations further than others. Instances are on record where over 100 years ago foundrymen strengthened their mixtures by the addition of wrought iron. These instances and others dealing with the subject up to modern times have been described in many papers and have been published in the technical press so there is no need at this time in presenting a review. Among the more

*Utah Copper Company.

prominent contributors on the subject are the late H. E. Diller, James A. Murphy and David McLain. The last named gentleman probably has done more than any other man in disseminating information on this subject among foundrymen.

Early Experiments

Little was heard of semi-steel before the early seventies when several Pittsburgh foundries tried it in their mixtures for castings requiring great strength. In the early eighties both Robert E. Masters and the late Thomas D. West contributed articles to the SCIENTIFIC AMERICAN describing their experiences in melting entire heats of steel scrap in the cupola. They claimed complete success in the actual melting operation, the metal was fluid and filled the molds readily, but the castings were hard and in the form they were poured found no commercial application. In recent years the only published material on the subject of melting entire heats of steel scrap have been confined to electric furnace operation.

For many years the writer has been accustomed to the continual use of steel scrap in cupola operation, from 10 to 15 per cent of light and medium weight and from 20 to 25 per cent in heavy machinery castings. A series of tests conducted over a period of many years indicate that the best results are secured from a mixture containing not over 30 per cent steel.

As stated previously instances are on record of entire heats of steel melted in the cupola, but these heats were comparatively small. Up to the present and outside of the author's own experience he has found no record of large heats melted in this manner.

Both in the past and present vastly different opinions prevail on the proper method of charging steel in the cupola. Our practice differs from any we have seen practiced or described. "The open mind is the precursor of progress." To accept some of the fundamental principles here presented in melting steel scrap you may find it necessary to revise some of the former conceptions of cupola practice.

Pure science is based on four fundamental principles: Analysis, synthesis, imagination and absolute elimination of personal

opinion. No person can say which of the four is the most important, but one in particular represents the sum total of the difference between scientific and unscientific methods.

Science Deals With Facts

When the average man untrained in the habit of scientific thinking approaches a problem he is swayed and influenced by preconceived opinion, prejudice, bias, habit and ignorance.

Science deals with nothing but facts, has no opinions, admits no prejudice, eliminates personal habits, analyzes to the last atom and admits nothing as a fact unless it stands the test of logical reasoning. A natural rule of action, a definite cause precedes every result.

Bearing in mind the foregoing points the writer approached a problem a few years ago of reducing an accumulation of approximately 12,000 tons of a poor grade of steel scrap into a commercial grade of hard iron castings. He had choice of three alternatives. To build an open hearth furnace, to install a large electric furnace or to attempt the melting of this large amount of steel in the cupolas already in existence. In addition to the 12,000 tons of steel scrap provision had to be made for taking care of a considerable tonnage of steel scrap incident to the operation of a large plant from day to day. The open hearth furnace and the electric furnace were ruled out on account of the heavy initial capital expenditure.

Attempt to use this immense amount of steel scrap by mixing it with the iron charges would not cut down the pile rapidly enough so it was decided to try the problematical process of melting complete steel heats. The attempt was made in the face of a prevailing opinion that the cupola lining, any kind of a lining would not stand up to the increased temperature considered necessary for melting steel. Resulting experience seems to indicate that the majority of failures in melting steel are due to misconception on this point.

Mistaken Ideas

New standards had to be developed to insure a metal throughout the duration of the heat of sufficiently high temperature to stand transportation a considerable distance and pouring over the

lip of the ladle. An impression prevails in some quarters that where steel is melted in the cupola the amount of fuel has to be increased over that required for gray iron on account of the higher temperature demanded. Otherwise it is claimed the metal will become pasty, set rapidly and skull the ladle. Also it is claimed that the steel absorbs carbon from the fuel, therefore the extra fuel is required to supply this carbon. Neither of these claims has been substantiated in our experience of several years in melting daily complete charges of steel scrap varying from 25 to 30 tons.

Early experiments with coke of 84 to 86 per cent fixed carbon and a high ash content showed that this coke was not capable of producing the necessary high temperature, irrespective of the amount employed. Finally we secured a coke of not less than 90 per cent fixed carbon and a low ash content. This coke produced satisfactory melting conditions and reduced the amount of slag to a gratifying extent.

We have four cupolas in our foundry and in our early experiments we melted the steel in the small pair lined to 45 inches. At that time the heats did not run over 15,000 pounds. At present and for the past two years we have been melting heats of over 30 tons daily for 7 days a week in the larger pair lined to 54 inches. The two cupolas are used on alternate days, one in blast and one under repair.

In preparing the cupola for a heat the lining is rebuilt or repaired to a straight line with silica split brick. The joints are made tight to prevent leakage of the gas. Several foundries melting steel were investigated in an attempt to discover a suitable lining. One was found in the Chicago district using a rammed ganister lining, but the heats were small and did not offer a fair comparison, since we were confronted with the problem of melting between 25 and 30 tons a day.

Many Lining Materials

After trying many forms of lining including ganister, magnesite and a few heat resisting cements warranted in advance to withstand high temperature and abrasion, the best results were secured from a split silica brick laid against a silica block backing.

At first we had a great deal of trouble with the slag hole. We tried chrome brick blocks, different kinds of mixtures including graphite, a proprietary cement, ganister and clay singly and in combination, but none lasted beyond the time of melting 30,000 to 40,000 pounds of metal. The hole became too large. Finally we developed a tap and slag hole formed from block silica brick with a daubing of 75 per cent silica sand, 2 per cent cement and 23 per cent good fire clay.

The first linings burned out quickly in the form of foam that came through the charging door, but we found later this was due to the manner of charging. Reducing the amount of high silicon-ferro alloy did away with this trouble.

The hearth is well rammed with a good mixture of silica sand and molding sand. This mixture is rammed hard around the edge, but not so hard in the center. The sand is struck off flat with a fall of one inch to the foot from the back to the spout. Three feet of coke are placed on the wood and a mild blast is employed until the coke shows red on top. The single row of tuyeres is located 20 inches above the bottom and after the coke is burned through we add a sufficient amount to bring the top 30 inches above the tuyeres. Charging then is commenced.

Steel scrap and coke are brought to the door in cars and charged by hand up to a point 3 feet below the door sill. The remainder of the material is dumped from the cars directly into the cupola by a mechanical charging device.

Small Charges

Instead of the usual 3300-pound charge we cut it in two and place a layer of coke between steel charges of 1650 pounds each. We have melted 3300-pound charges, but found that the metal from the smaller charges is more conveniently handled and carries a higher temperature.

Scrap used in the charge is made up of nearly everything in the steel line either forged, rolled or cast. Structural shapes, plates, rods, railroad scrap, rails, fish plates, bolts either in the natural state or cut to convenient handling lengths. Chunks of high manganese, high and low carbon steel up to 150 pounds in weight are charged intact.

Competent converter steel men advised the writer in the beginning that the addition of high silicon ferro-silicon in lump form was absolutely essential to raise the temperature and fluidity of the metal to a point where it could be poured satisfactorily over the lip of a ladle. Experience has shown this advice to be mistaken. The practice of using a rich grade of ferro-silicon probably ranks next to the high fuel ratio mentioned previously

Table 1

CHARGING DATA

No. 7—Whiting cupola (lined to 54 inches inside diameter)
Coke on Bed Charge 1,900 pounds
Steel on charge (full charge on bed) 3,300 pounds
Coke on charge (full charge) 341 pounds
Steel on charge (half charges) 1,650 pounds
Coke on charge (half charges) 171 pounds
Melting ratio 1 to 7.5
Lime rock (half charge) 75 pounds
Pressure of blast, 14 to 15 ounces
Maximum amount of air per minute 6,000 cubic feet

PHYSICAL TEST DATA OF METAL

Bars left in flask until cold	Brinnell Hardness Best averages	Transverse Test	Deflection in inches
Bar 5	600	3,300	.08
Bar 6	600	3,428	.08
Bars quenched in water			
Bar 5		1,420	.07
Bar 6		1,130	.05

Note: A great deal of experimental work was done on the use of fluxes of a high per cent of fluor spar. A high per cent of fluxing material was necessary because the scrap material contained a great deal of corroded material, with fine crushed ore resembling cement adhering to the scrap. This combination was very destructive to the lining and after much experimentation the use of fluor spar was abandoned and there was adopted as a standard the use of 150 pounds of lime rock to the full charge (3,300 pounds) and with spit charges 75 pounds of lime rock. This amount of flux causes slag flow with comparatively no mineral wool expelled from the slag hole.

as the principal cause of failure in melting steel heats successfully in the cupola.

Cost of this high grade material is much higher than ferro-silicon of a lower silicon content and in that manner the expense of operation is increased beyond reason. Further, 80 per cent ferro-silicon limits production since it creates a slag that quickly eats out the lining of the cupola.

While trying the high ferro-silicon, the limit of the melting capacity of a 45-inch cupola was 15,000 pounds. After 7 months of trial and experiment we gradually cut down on the ferro-silicon and transferred the steel melting to our two 54-inch cupolas and gradually raised the daily charge until we attained our present maximum of 62,000 pounds, sufficient for present requirements.

Under former conditions an addition of from 4 to 15 per cent gray iron pig or scrap had to placed in the mixture at the beginning of the heat to prime it and prevent it from chilling in the tap hole. Under the conditions finally developed we use no soft iron whatever and experience no trouble of any kind with the tap or slag hole or with the lining of the cupola.

Fumes From Metal

An unexpected problem arose when we raised the steel heats to 20,000 pounds. When we tapped out into the spout ladle, the metal created so much smoke and fumes that it affected the cranemen, the eyes and throat of the charging floormen and no one could work near the cupola, causing a lot of waste space.

We erected a large hood with a thirty inch stack, but it did not wholly relieve the situation After giving it a good deal of thought, the writer dropped one piece of aluminum weighing 4 or 5 ounces in the spout ladle, "before taping out," and a piece in the ladle about the middle of the tap, this caused a reaction and did away with the smoke entirely. This method is in practical use at the present time.

The Resulting Metal

Naturally at this point the question arises what kind of metal is produced in the foregoing manner from an all steel charge. For our purpose we needed a metal to resist abrasion, to wear down uniformly without cracking or spalling. Our product is low in silicon and manganese and has a brinell hardness of 600 to 712. We had no need for a synthetic or machinable gray iron, therefore no effort was made to secure an iron of that character.

Synthetic cast iron has been made from steel charges in electric furnaces and in small experimental cupolas at various universities, but definite information seems to be lacking in the detail of operation. Results, particularly in recarburization, have not been positive. Introduction of silicon into the charge will increase the silicon content, but at a corresponding reduction in the amount of carbon. The most satisfactory method of raising the carbon content appears to be through the addition of ferrochrome.

Written Discussion—By Frank Hudson,* Wyoming, Pa.

I would like to confirm Mr. Jennings paper in its entirety, and furthermore to state that the best cupola melted iron that I have ever seen was produced from an all steel mix. This synthetic iron was made for the purpose of remelting for high duty castings, such as locomotive cylinders and Deisel engine castings and very often locomotive piston valve liners were cast direct. The general practice of bringing the iron up to the required analysis was to have about 25 per cent of the charge consisting of 6 per cent silicon low phosphorus pig and 75 per cent steel but at times this pig could not be obtained and then 100 per cent steel was used together with ferro-silicon and ferro-manganese additions.

About 20 tons of this iron was melted daily and a few points about the melting practice may be of interest.

1. Silica bricks found most durable in melting zone.
2. Whiting cupola lined to 45 inches inside diameter with rated capacity of 8 tons per hour. Ratio of tuyere area to cross sectional area of melting zone 1 to 3.8.
3. Coke on bed charge 2,240 pounds.
4. All steel charges used weighed 2,240 pounds.
5. Coke on charges weighed 280 to 308 pounds according to the condition of the steel being melted, whether light shearings or plates, etc.
6. Melting ratio excluding weight of bed coke 1 to 7.4.
7. Fluxing material 56 pounds limestone and 28 pounds manganese ore per charge.
8. Pressure of blast about 26 ounces. Amount of air used about 3,600 cubic feet per minute according to the condition of the steel scrap used.

*Assistant Superintendent, Wyoming Shovel Works.

9. Average analysis of resulting iron using 16 pounds of 80 per cent ferro-manganese and 60 pounds 50 per cent ferro-silicon

T.C.	Si.	Mn.	P.	S.
3.00	1.02	1.23	.086	.082

The ferro-manganese and large chunks of ferro-silicon were added in the cupola with each charge and about 10 pounds of ferro-silicon out of the 60 pounds added as dust in the cupola spout to take care of oxidation. No trouble was ever experienced from dull iron. In fact the metal as a rule was much hotter when melting all steel than when running ordinary soft iron mixtures. The average spout temperature being 1,400 degrees Cent.

FIG. 1—ALL STEEL MIXTURE CAST IRON—MAGNIFIED 50 DIAMETERS

A great deal of ferro-silicon is lost through oxidation and the better practice finally found was to use a larger quantity of 5 to 6 per cent silicon low phosphorus pig on the charges.

The resulting iron machined well, giving a tensile test of 40,320 pounds per square inch to 47,000 pounds and a transverse test of 15,680 pounds deadload with .11 inch deflection on a 14 by 2 by 1 inch bar broken over 12 inch centers through the 1 inch side. The resulting iron is shown in the micro-photograph.

All the molds cast with this material were cast hot and formed of dry sand and I know of instances where railroad inspectors had hesitated to accept these high test castings thinking that the stuff was not real cast iron.

A Study of Iron Melted in a Cupola

By R. E. Wendt[1] and J. P. Walsted,[2] La Fayette, Ind.

Cupola operation offers many problems. The difficulty of visual observation of the reactions during melting and the wide variation in cupola management has led to many conflicting opinions as to what happens in the cupola when the charge is being melted. Much of the information published is based upon scientific facts. When, however, one considers the large number of variable factors and the difficulty of checking or controlling them, it is not surprising that foundrymen cannot agree.

Steel making in the open hearth furnace can be controlled and uniform steel can be produced by checking the refining process while it is in progress. This is not true in melting gray cast iron in the cupola furnace. Calculations can be made before charging the cupola and a certain amount of control accomplished in this way, but once the charge is made up and the blast turned on, the foundryman must take what he gets at the spout.

Several investigators have published the results of researches on this subject. Among these is Belden of the Bureau of Mines.[3] Belden located the melting zone in the cupola at that portion of the shaft where the lining most rapidly wore away. In arriving at this conclusion he made use of the analysis of the gases found at various zones in the cupola and also the temperatures. The work of Belden was ably done and a valuable addition to the literature, even though later work proved his conclusions to be erroneous. While the wearing away of the lining undoubtedly indicates the zone of highest temperature, there can be no doubt that temperatures high enough to melt iron are found much higher in the shaft.

Grennan[4] made use of windows set in the side of a small cupola in order to observe the progress of the melting. In this

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[1] In charge of Foundry Instruction, Purdue University.
[2] Research Assistant Engineering Experiment Station, Purdue University.
[3] Belden—Bureau of Mines Bulletin 54.
[4] Grennan, J.—Visual Observation of Melting in a Cupola, Trans. A. F. A., vol. 31, pp. 101-109, 1924.

way he was able to prove conclusively that much iron is melted before it reaches the theoretical melting zone. Later, by means of the same ingenious arrangement, Grennan observed the melting of steel scrap in the cupola.[5]

Dr. R. Moldenke[6] used Cuban pig iron in a charge of iron and proved by the analysis of the resulting melt that several charges in a cupola will mix. The purpose of Moldenke's experiment was to study the cupola operating with the mixture changing during the heat. E. J. Lowry in discussing Moldenke's work stated that the mixing of charges in the cupola is due to piling of charges on each other on the hearth and not to uneven melting. He also stated that by tapping out one transition tap of metal all mixed metal will be drawn off. In view of the results obtained by Moldenke, Lowry's statements seem to not be justified.

The commonly accepted belief that an extra charge of coke between charges of varying composition is enough to keep the two charges separated has never been proved and for that reason is open to question.

Experimental Work at Purdue University

The research discussed in this paper was undertaken with the idea of gaining some information on the subject of cupola opertion. During an experimental heat consisting of only one charge of iron it was found necessary to use a cover charge of coke to retard the blast. Without this cover charge the blast passed through under low pressure and so rapidly that most of the heat passed out with the gases. In order to further retard the blast a few large flat pieces of pig iron and large pieces of scrap were piled on top of the coke. This cover charge of iron was 36 inches above the melting zone in the 27-inch cupola, yet when the bottom was dropped it was found that much of the cover iron had melted. Several large pieces of scrap had entirely

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[5] Grennan, J.—Melting Steel in a Cupola, Trans. A. F. A., vol. 32, pp. 448-463, 1925.

[6] Moldenke, R.—Cupola Melting Tests with Mixtures Changing During Run, Trans. A. F. A., vol. 30, pp. 159-164, 1923.

melted while several pigs of thick section were as much as one-third melted. After this occurrence no reason was seen for believing that all melting takes place at that zone where the lining wears away most rapidly.

With all the evidence presented it seems likely that there may be some variation in the composition of a regular gray iron heat from the first to the last of the heat. It would be of some value to know how this uneven melting affects foundry practice.

Table 1

Log of Heat

Blast On	2:18
First iron	2:25
First tap	2:32
Blast off	3:01

Charges	*Pig Per Cent*	*Scrap Per Cent*
1	0	100
2	50	50
3	50	50
4	50	50
5	50	50

Bed coke	325 pounds
Coke between charges	60 pounds
Iron charges	500 pounds

Table 2

Pig Iron Analysis

C per cent	S per cent	Si per cent	P per cent	Mn per cent
3.71	.034	3.00	.536	.534

The regular gray iron heats used for class demonstration were used to obtain specimens for this problem. These heats were made up of four to six charges of five hundred pounds each. In these heats the first charge is usually made of return scrap and sprues and is cast into sash weights and paper weights. This is done to get rid of the large amount of return scrap that naturally accumulates in a school foundry. The remaining charges are 50 per cent scrap and sprues and 50 per cent pig iron. This iron is cast into the various pieces used by students as exercises in machine shop practice.

The cupola is 27 inches in diameter, 90 inches from the tap hole to charging door. The tuyeres, six in number, are 10 inches above the sand bottom. The tuyere ratio is 1 to 4.5. The blower is of the positive pressure type. A mild blast 6 to 7 ounce pressure was used in these investigations.

Table No. 1 gives the log of a heat used in the research and is typical. These figures are presented in order to give an indication of the rate of melting.

In the demonstration heats approximately 500 pounds of metal are drawn off at each tap. The iron is poured by means of 75-pound ladles filled at the receiving ladle. The receiving ladle is not used as a mixing ladle but it is emptied after each tap.

In these heats the blast is started with the tap hold open, the first iron being allowed to run out. When the iron appears hot enough to prevent freezing up at the tap hole, the furnace is plugged and the iron allowed to pile up on the hearth.

It will be seen from Table 1 that the first iron appeared at the spout seven minutes after the blast was started. Approximately seven minutes elapsed between taps. With taps of five hundred pounds this gives a melting rate of a little over two tons per hour for the 27-inch cupola.

To obtain specimens for this investigation one pair of test bars, 1 inch by 1 inch by 14 inches, was cast from each tap during the five heats. After shaking out, they were cleaned with a wire brush and tested without further treatment. Physical tests were transverse, deflection and hardness (Brinell). The transverse testing was done on a Reihle Bros.' testing machine on supports twelve inches apart. The load was applied according to the A. S. T. M. specifications as found in the A. S. T. M. year book of 1924. All bars were tested with the cope side uppermost. The Brinell hardness specimen was cut from the fractured bar near the fracture, the impression being made at the center. This, of course, is the softest part of the specimen and the part most subject to sponginess. However, the conditions affecting the quality of the iron at the center are more constant and the center position was chosen for that reason. Table 4 gives the results of physical tests.

One-half of each test bar was drilled through from top to bottom and shavings from duplicate bars mixed. The analyses of these shavings were taken as the analysis of the tap from which the bars were cast. Table 3 gives the results of these analyses.

The curves of Figs. 1 to 5, inclusive, were plotted from the data of Table 3.

Table 3

Analysis of Heats

Tap	C per cent	S per cent	Si per cent	P per cent	Mn per cent
HEAT No. 1					
1	3.27	.079	2.26	.854	.401
2	3.41	.081	2.45	.637	.402
3	3.41	.071	2.54	.585	.445
4	3.46	.058	2.46	.660	.452
HEAT No. 2					
1	3.38	.086	2.17	.682	.382
2	3.40	.072	2.16	.599	.431
3	3.36	.087	2.27	.653	.443
4	3.31	.076	2.29	.684	.445
5	3.38	.076	2.24	.736	.423
HEAT No. 3					
1	3.18	.074	2.20	.956	.342
2	3.12	.061	2.42	.740	.329
3	3.27	.071	2.39	.709	.332
4	3.30	.077	2.41	.760	.407
5	3.31	.063	2.41	.650	.424
6	3.31	.057	2.72	.658	.442
HEAT No. 4					
1	3.31	.074	1.92	.614	.326
2	3.29	.058	2.33	.650	.368
3	3.40	.079	2.52	.670	.385
4	3.41	.070	2.88	.618	.427
5	3.44	.060	2.93	.621	.447
HEAT No. 5					
1	3.31	.074	2.23	.737	.322
2	3.35	.069	2.26	.713	.345
3	3.40	.075	2.46	.713	.345
4	3.45	.072	2.56	.626	.372
5	3.53	.072	2.58	.658	.372

Table 2 gives the analysis of the pig iron used. It was impossible to determine the composition of the scrap but the analysis of the first tap should give at least an approximation of the composition.

The curve of Fig. 1 shows a gradual increase in carbon from the first to the last of the heat. The curve of Fig. 2 shows that sulphur gradually decreased during the heat. The curve of Fig. 3 shows an increase in silicon content as the heat progressed.

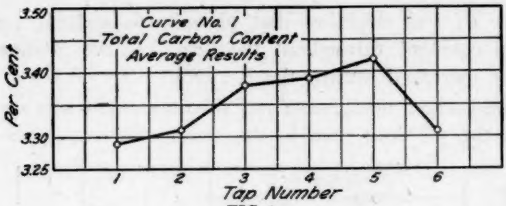

FIG. 1

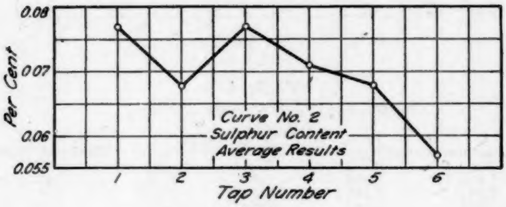

FIG. 2

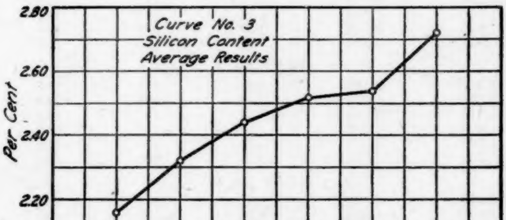

FIG. 3

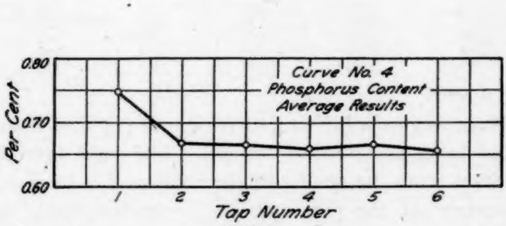

FIG. 4

The curve of Fig. 4 shows that phosphorus content remained practically constant throughout the heat. Curve 5 shows that manganese increased toward the last iron.

As the carbon, manganese and silicon content was somewhat higher in the pig iron than in the scrap, the results show that

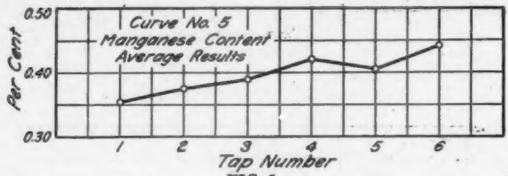

FIG. 5

Table 4

Physical Test Results of Bars

Tap	Transverse Strength, pounds Bar 1	Transverse Strength, pounds Bar 2	Deflection in inches Bar 1	Deflection in inches Bar 2	Hardness, Brinnell Scale Bar 1	Hardness, Brinnell Scale Bar 2
			HEAT No. 1			
1	2,430	2,220	.105	.093	187	179
2	2,235	2,340	.115	.140	179	163
3	2,290	2,310	.120	.120	149	170
4	2,135	2,220	.099	.100	179	163
			HEAT No. 2			
1	2,225	2,350	.105	.112	163	170
2	2,235	2,090	.110	.110	159	153
3	1,960	1,910	.109	.098	140	131
4	1,925	2,010	.100	.078	149	156
5	1,820	2,320	.085	.106	156	159
			HEAT No. 3			
1	2,390	2,455	.112	.113	179	192
2	2,090	1,830	.106	.086	149	149
3	1,955	1,960	.103	.101	143	143
4	1,825	1,975	.114	.110	131	134
5*	1,945	2,225	.110	.120	126	121
6	2,240	1,945	.112	.098	143	137
			HEAT No. 4			
1	2,470	2,790	.106	.132	196	196
2	2,075	1,925	.130	.101	149	156
3	1,925	2,260	.100	.117	131	126
4	2,020	1,840	.108	.100	149	89*
5	1,890	2,135	.111	.120	156	143
			HEAT No. 5			
1	1,915	2,000	.091	.086	163	179
2	2,225	2,125	.124	.117	170	170
3	2,230	2,195	.135	.107	143	149
4	2,020	2,010	.111	.121	156	166
5	2,400	2,433	.142	.116	143	170

*Spongy at center.

the last iron contains a higher proportion of pig iron than would be expected from the mixture charged. The same inference can also be drawn from the results of the analysis for sulphur, as the sulphur content of the pig iron was somewhat lower than the scrap.

Table 5

Results of Tests on Commercial Cast Iron

HEAT No. 1

Size of charge	5,060 lbs.
Pig iron	1,590 lbs.
Return scrap	710 lbs.
Foreign scrap	2,760 lbs.
Coke bed	425 lbs.
Coke between charges	80 lbs.
Height of tuyeres above sand bottom	18 inches

Analysis	First of heat	Last of heat
C (total)	3.120	3.040
S	0.102	0.107
Si	2.050	1.870
P	0.537	0.685
Mn	0.377	0.406

Physical tests	First of heat	Last of heat
Transverse (lbs.)	2,425	2,800
Deflection (inches)	.127	.134
Tensile (lbs. per sq. in.)	17,850	25,750

HEAT No. 2

Size of charge	5,245 lbs.
Pig iron	1,570 lbs.
Return scrap	825 lbs.
Foreign scrap	2,850 lbs.
Coke bed	425 lbs.
Coke between charges	80 lbs.

Analysis	Middle of heat	Last of heat
C (total)	3.060	3.110
S	0.121	0.116
Si	1.690	1.450
P	0.600	0.603
Mn	0.407	0.368

Physical tests	Middle of heat	Last of heat
Transverse (lbs.)	2,800	2,900
Deflection (inches)	.129	.128
Tensile (lbs. per sq. in.)	24,070	27,610

HEAT No. 3

Size of charge	4,500 lbs.
Pig iron	1,400 lbs.
Return scrap	500 lbs.
Foreign scrap	2,600 lbs.
Coke bed	425 lbs.
Coke between charges	80 lbs.

Analysis	First of heat	Last of heat
C (total)	3.160	2.920
S	0.140	0.127
Si	1.900	1.590
P	0.546	0.653
Mn	0.457	0.390

Physical tests	First of heat	Last of heat
Transverse (lbs.)	2,350	3,100
Deflection (inches)	.107	.135
Tensile (lbs. per sq. in.)	21,650	27,680

These results indicate that the small scrap is all melted and removed from the furnace before the pig iron of the last charge is melted. The sprues and light scrap which make up a considerable portion of every heat in commercial practice will be found mixed with the iron of charges lower in the furnace. The first tap will contain almost all scrap iron while succeeding taps will contain increasing percentages of pig iron. The last tap will contain little or no light scrap.

In view of the foregoing it is recommended that the first tap be cast into such castings as will be satisfactory if made from all scrap iron, while castings requiring a large proportion of pig should be saved until the last and be cast from the last one or two taps.

In addition to the samples cast in our University foundry, samples were obtained from a small commercial foundry. This foundry is a small shop but enjoys a very good reputation for manufacturing high quality gray iron castings.

Analysis of these samples showed a variation at various stages of the heats. No analysis of the scrap or pig used in making these castings was available. The transverse test was made on the 1 inch by 1 inch bar 14 inches long, cast vertically and tested on supports 12 inches apart. Tensile tests were made on bars 1½ inch round cast vertically and then machined to 1⅛ inches round at the center. The bars were not rattled or treated in any way after casting. These tests are not standard but as only the comparison between the various stages of the heat was required they served very well to obtain values for comparison. The results obtained are shown in Table 5.

It can readily be seen that the iron cast in these three heats varies somewhat in composition as well as physical properties at different parts of the heats.

Conclusions

It has been shown that iron in the cupola will melt much higher up in the stack than what is usually called the melting zone, especially when the charges are made up of very light or thin pieces, such as gates and sprues mixed in with heavy pieces such as pig iron, even if the light pieces are put on top of

the heavy ones. The thin pieces will melt first and run down in between the coke and mix with the iron in the preceding charges. This gives a non-uniform product, more scrap iron finding its way into some charges than others, leaving more pig iron in some of the charges than was calculated on when computing the mixture.

How the small pieces of iron can be prevented from melting higher in the stack and sooner than the pig iron is more than the authors are able to say. But it is a well known fact that a heavy layer of coke between layers of iron will not prevent it from melting first.

Cupola irons have a reputation of not being the most reliable irons to base on in engineering work. One can very easily see the reason for that when one takes into consideration how most of the cupola charges are made up of different sized pieces of iron in a charge and how the iron is tapped out of the cupola.

Cupola irons may be made more uniform by changing the method of charging usually followed by most foundries. One way to improve the product is to charge irons in each charge that is uniform in size and by not making the layers of iron too large to a charge. Another way is to have the tuyeres in the cupola much higher from the sand bottom than is usually the case, so that a large body of metal may be held in the cupola before a tap, thus allowing several charges to be melted and run together before a tap is made.

In closing, it may be stated that the investigation is very instructive and interesting as far as it has been carried out. However, so many factors influence cupola practice that many more experiments must be made before a complete knowledge of cupola operation can be obtained.

Written Discussion—By A. C. Porter, Lincoln,* Neb.

This study of iron melted in the cupola is very interesting and instructive insofar as it applies to the specific conditions as stated by the writers. The articles and papers referred to, viz.:

*Foundry Supt., Cushman Motor Works.

"Visual Observation of Melting in Cupola," "Melting Steel in a Cupola," both written by J. Grennan, and "Cupola Melting Tests with Mixtures Changing During Run" by R. Moldenke, are very commendable, and together with this study of iron melted in the cupola, are representative of a great deal of constructive thought.

However, from my personal viewpoint, gained through an extensive study of different cupolas operating under changing melting conditions in the East, South and Middle West, it seems apparent that one vital factor has not been taken into consideration during these investigations, at least, very little mention has been made of the actual melting conditions under which these cupolas were operating at the time referred to. All foundrymen melting iron in a cupola realize how sensitive to varying conditions this melting medium is.

If the melting conditions were all the same and every cupola was operated the same, and metal charges could not be kept separated any better than these investigations show, it would be impossible for the metallurgist, or foundryman to calculate different mixtures and be able to have metal poured into the molds anywhere near the estimated analysis. This, however, we know is being accomplished. It would seem that a study as outlined in this paper would be of universal interest, if it could be made under different melting conditions and a comparison made.

At our plant in Lincoln, Nebraska, we run three and four different mixtures through the cupola every day, silicon ranging from 1.04 to 2.40 per cent, and total carbon from 3.20 to 3.60 per cent. We do not use extra coke to separate the charges, but we feel that we are melting our iron under as near the correct conditions as possible; for example, our cupola is lined to 36 inches inside diameter and the distance from top of tuyere to charging door is 8 feet.

With this short preheating space, we find that a tuyere ratio of 1 to 3.5 gives the best results. Our blower data are:

Roots Blower No. 3. Displacement 8.3 cubic feet per revolution.
R.P.M. 300, delivers 2,508 cubic feet of air per minute—150,360 cubic feet per hour.

Allowing 10 per cent loss of air for friction and leakage, we figure 135,324 cubic feet of air as being actually delivered to the inside of the cupola. Carbon in the coke we use runs from 90.35 to 91.60 per cent.

We take the theoretical amount of air necessary to burn one pound of carbon to be 137 cubic feet—then, by delivering 135,324 cubic feet we must have sufficient incandescent carbon charged to keep the percentage of CO_2 gas as high as possible. Under these conditions, the necessary amount of carbon to be charged is found by calculation to be 987 pounds per hour.

By using the following formula, we proportion our charges as follows:

$$\frac{\text{Pounds carbon required per hour}}{\text{Per cent carbon in coke}} = \text{pound coke required per hour.}$$

$$\frac{\text{Total tonnage per hour}}{\text{Weight of each metal charge}} = \text{Number of charges per hour.}$$

$$\frac{\text{Pounds coke per hour}}{\text{Number charges per hour}} = \text{Pound coke per charge.}$$

The amount of coke used on the bed is not stated because this amount varies according to the volume and velocity of air blown into the cupola, and its velocity is governed by the tuyere area.

By operating our cupola on this basis, we know just how many minutes it takes to melt each charge of iron, and the full charge is tapped accordingly. This is our method and we have proof at our plant in the form of analysis cards made by our consulting metallurgist that our charges do not mix.

As stated above, it would seem that the study of the process of melting in the cupola could be undertaken to the great advantage of all concerned in the use of the cupola as a melting medium, if it is possible, to ascertain just what the melting conditions are under which the study or investigation is made.

Core Supports in Large Castings*

By Ivan Lamoreux,† Liege, Belgium

The use of core supports in molding large pieces gives rise to numerous accidents that it is very difficult to avoid completely. By examining the reactions of the core support during casting, we shall try to evolve instructions for the founder.

Core supports must resist the crushing forces, resulting from the pressure exerted upward by the metal by virtue of Archimedes' principle.

This resistance would be simpler to calculate if it were only a question of a normal force, but the pressure almost always is exerted under very unfavorable conditions. In reality, the high temperature of the tapped metal surrounds the support and, by progressive heating of it, lessens its powers of resistance.

In addition, it sometimes happens that leaks of metal occur at the joints of the flask or at the cored points and, in order not to lose the casting, pouring is continued until the leak stops; during this time, the inflow of hot iron injures the supports placed over the passage situated between the gate and the riser and places them in the most unfavorable conditions for resistance. If the support is of mild steel it will bend, and if it is of cast iron it will crack (see Fig 1).

Welding of chaplets has been mentioned frequently. We do not think that iron (mild steel) can actually be welded to cast iron, at least in large masses. A *perfectly sound intimate contact* can be obtained, but on condition that an iron is used that is sufficiently liquid to give a sound casting, but not hot enough to hinder the reactions producing it. It has been stated that mild steel, immersed in the cast iron, causes the reactions.

Certain founders, when they pour large frames, conceive of reinforcing the journals by immersing a rod of mild steel inside them (see Fig. 2). As the metal must be very hot in order to follow the mold surfaces, without solidifying, it causes bubbling around the steel rod with a resulting porous region. If, in spite

*Presented in behalf of the Belgian Technical Foundry Association.

†First vice-president of the Association Technique de Fonderie de Belgique.

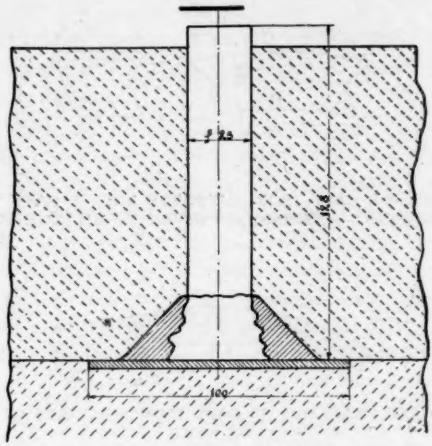

FIG. 1—SHOWING CRACKING OR BENDING OF CORE SUPPORT

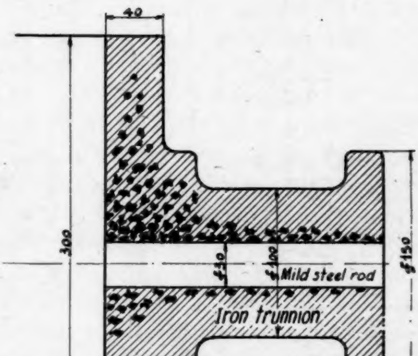

FIG. 2—SHOWING POROUS CONDITION OF CASTING WHEN STEEL RODS ARE USED FOR REINFORCEMENT

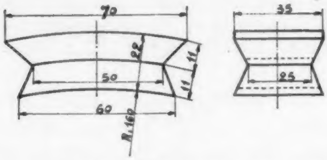

FIG. 3—DESIGN OF CAST IRON SUPPORTS WHICH GAVE TROUBLE BY CRACKING—DIMENSIONS GIVEN IN MILLIMETERS

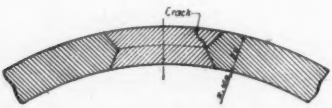

FIG. 4—SHOWING CRACKING OF CAST IRON SUPPORTS OF THE DESIGN OF FIG. 3

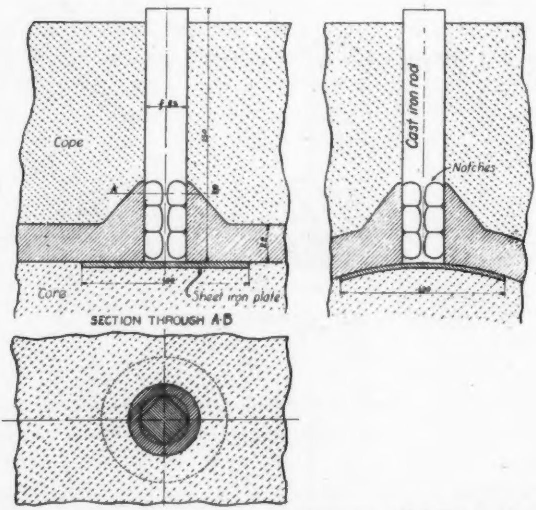

FIG. 5—USE OF NOTCHED CAST IRON RODS TO SUPPORT CORE—THESE RODS SUPPLANTED THE USE OF THE SUPPORTS SHOWN IN FIG. 3

of this porosity, the mild steel rod remains intact in the casting, the soundness of the journal will be sufficient, but by contact with the metal containing carbon, it receives and absorbs part of this carbon, and as cooling is rather slow, the mild steel recarburizes and becomes brittle.[1]

An end contrary to that sought is thus reached. The same thing is true of bedplates consisting of a cast-iron slab in which mild steel eyelets have been buried; if this piece is subjected to a lateral stress, there is great risk of breaking the eyelets off even with the slab. It is found, in case of rupture, that the fracture is crystalline, brilliant, and not fibrous and dull as the steel appears before having been embedded in the iron. Some examples taken from current practice will make evident the dangers to which one is exposed and the solutions that experience has indicated.

Pipe for chemical factories. A foundry had made a series of 48 U-formed pipes about 2.5 meters long and 320 millimeters in diameter, and 22 millimeters thick. These pipes had to resist the action of hot gas under pressure and consequently had to be absolutely tight. Curved cast double supports had been used, according to design No. 3, and in use leaks were found at these supports; leaks that they tried in vain to stop. Upon sawing through a support, a pulling apart was found, caused by the shrinkage of the pipe, the knife-shaped part of which had compressed the support as in a pair of shears (see Fig. 4).

To remedy this condition absolutely clean cast iron rods were connected and notches made in them (see Fig. 5); then this support, covered with sand, was rested on a sheet-iron plate fixed in the core, then fastened above by the ordinary methods.

During casting, the iron having escaped by this connection, pouring had to be continued for some minutes to keep the mold full. As a consequence of the considerable heating due to the flow of the iron, the support collapsed and the core rose, making the piece useless.

The solution was found by using a cast iron rod, 50 millimeters in diameter, with a sharp-angled thread of about 6 millimeters, as in Fig. 6. If it happens that the iron is a little cold

[1] Experience of William & Arnold.

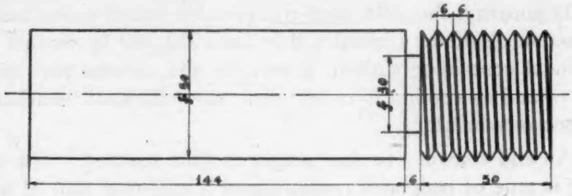

FIG. 6—THREADED CAST IRON ROD—DIMENSIONS GIVEN IN MILLIMETERS

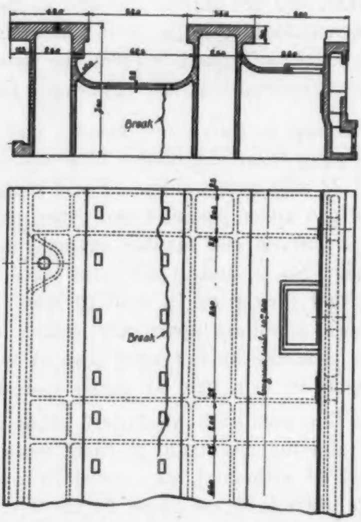

FIG. 7—LATHE BED WHICH CRACKED BECAUSE OF POOR CORE SUPPORTS—DIMENSIONS GIVEN IN MILLIMETERS

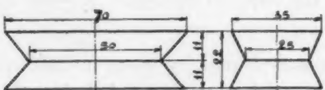

FIG. 8—DESIGN OF CHAPLET USED TO SUPPORT CORES OF LATHE BED FIG. 7—THESE CHAPLETS WERE REPLACED WITH SHEET IRON PLATES

and that a leak is discovered at the threaded rod, it is removed by unscrewing it and another rod, of mild steel of slightly greater diameter, is placed in the threaded hole. Thus if a piece is lost with ordinary supports, a good piece can be quickly made at small expense.

Lathe bed. In casting a 25-ton lathe bed measuring 12 meters in length and having the section shown in Fig. 7, it was decided to support the cores on strong supports, because of the great distance that the metal had to travel and of the position of the gate at tip end of the slides.

As a measure of prudence, cast iron supports, Fig. 8, were used and at the moment of filling the iron, rising slowly, lingered between the supports placed under the cores. A rapid cooling of the metal took place, the crystallization of which was very fine, causing a great shrinkage. The slow cooling of the sides caused a strain in the part where the supports were, and when the casting was out of the sand it broke along the line indicated.

This piece was finally turned out by using mild steel supports composed of two sheet iron plates joined by a cross-piece the mass of which only slightly affected the temperature of the metal and its circulation in the mold.

Conclusions

Dimensions. Proportions between the dimensions of the supports and those of the piece to be cast should be fixed in such a way as to realize a compromise with the resistance of the support *when it is surrounded by the cast iron* and to prevent rupture of the piece upon cooling.

Shape. In pieces subjected to hydraulic or other pressure, use threaded supports that permit soundness to be obtained. In other pieces, use the less costly supports of polygonal form.

Welding of supports. It is useless and dangerous to seek to obtain the welding of the supports, which cannot be approached except by modifying profoundly the composition of the metal.

On Gating Iron Castings

By H. W. Dietert,* Detroit, Mich.

The material presented in this paper clearly shows that there is a well founded skill in the foundry profession. This skill when applied to the gating of castings has been a very difficult one to describe and to pass on to the coming generation of foundrymen.

When a foundryman endeavors to explain the gating of castings to his associates, he gives a very lengthy explanation. Very often he must relate years of experience to convey his reasons. If the foundryman had concrete terms and numerical values with which to readily convey his knowledge of gating, he then could quickly pass information, gained by years of experience, to his associates. The result would be an enormous saving to the industry, due largely to eliminating the experimental gating period through which every foundryman passes.

The gating of castings is an art and is founded on certain basic principles. The work on gating as presented is based upon this conviction and on faith in the foundry profession.

Purpose of Discussion

A thorough knowledge of gating is possessed only by a limited number. This is undoubtedly due to the fact that each member of the industry must begin at the bottom and collect his knowledge of this art by the trial and error method. In fact, one is not far wrong in stating that gating knowledge is developed only after an active life service of a foundryman, or some thirty years. Progress is very slow where the new generation must start at the starting point of the old generation. Progress is building on and not continued rebuilding.

Marked progress will be made in gating when the existing principles of gating can be described numerically and not by the present broad verbal manner. The object of this paper is to encourage investigations of gating by presenting the numerical

*Engineering Dept., United States Radiator Corporation.

values for gates as found in various foundries. No new theories are developed as the data and charts describe conditions as found by an investigation of actual gates found in various foundries.

Presentation

No attempt shall be made to discuss the entire field of gating. However, an endeavor shall be made to show a few detailed facts which govern the gating of molds. The data and principles set forth are no more than the foundryman's gating skill converted into figures and charts. The charts are of a practical value because they show graphically the life time gating experience of a group of foundrymen. The amazing thing is not the mystery of gating, but the fact that the gating practices of a group of foundrymen, a number of whom have never met, agree fundamentally. Verbally, very few of the foundrymen would have agreed on gating principles.

Classification

The sprue and runner will not be discussed, for the gate alone offers sufficient material.

The skill of gating may, for the present, be classified into the following terms: a—Placing; b—Design; c—Size.

The placing of a gate is largely determined by a location on the pattern which will distribute metal and feed the mold with the least disturbance. Other conditions as available or allowable location enter in also.

The design of a gate is usually determined by shape which will fit the pattern and permit placing in mold, and other items, for example, ease of breaking off, feeding and effect on finish of casting.

The last classification, namely, size of gates, is a very important one and the remainder of this paper shall be devoted to conditions determining this.

Size of Gates

The size of a gate is controlled by its breadth and thickness. The dimensions of a gate should not be changed indifferently.

The thickness of a gate is very vital for it governs the feeding of the casting and the structure of metal at the section where the gate joins the casting.

The feeding of a casting through the gate will decrease as the casting thickness decreases and its breadth increases. The grain structure of the metal section where the gate is broken off will increase in size for thin walled castings as the thickness of the gate increases. In view of this the thickness of gate is limited to the stock of casting, if grain structure is of importance, particularly in hydraulic tested castings.

Here again we are confronted with endless descriptions. In order to attack this problem one must first know the area of the gate to be able to choose a certain thickness and breadth.

The area of the gate in square inches will serve as a starting point from which future developments can be made. It is the author's opinion that the principles governing the area of gates should be first determined. The area or size of a gate will determine the pouring time of a casting.

Pouring Time

Among the many things that a sound casting requires is that the mold should be poured in a fairly definite time. The pouring time or the time required to pour the mold, will determine the progressive setting of the iron and to a large extent the physical factors affecting the casting.

A progressive setting of the molten iron from the far end of the gate is desirable to decrease strains in the castings and prevent possible crevices. Many castings are lost due to the fact that the pouring time is not correct, thus subjecting the iron and mold to a severe test. If the mold is poured in the correct time then a large variation in iron and other conditions would be permissible. The pouring time of a mold may be easily found by using a stop watch to obtain the time in seconds required to pour the mold. In this manner one may obtain valuable information pertaining to correctness of gate size.

Stop watches are used in the foundries of the United States Radiator Corporation to obtain the pouring time of molds. The

weight of castings made in the foundries range from light plate work to large boiler castings weighing 1,000 pounds.

The pouring times for the various castings are shown graphically in Fig. 1 where the pouring time is plotted against the weight of castings. One may readily note that there is a direct relation between the time required to pour a casting and the weight of the casting. A remarkable part of these data is that such close relations and exactness were found in the various foundries.

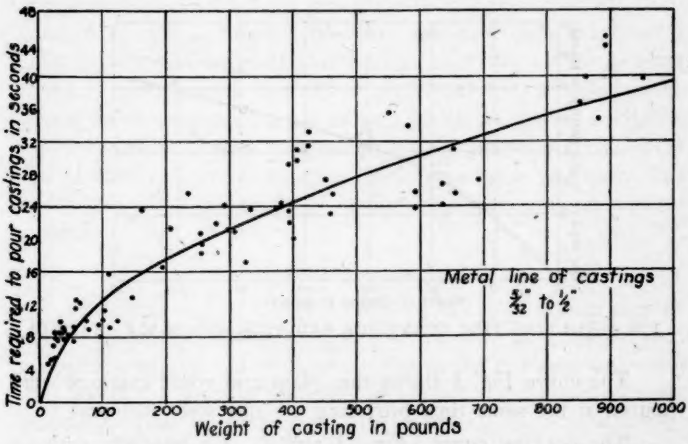

FIG. 1—POURING TIME CURVE FOR LARGE AND SMALL CASTINGS

A foundryman as a rule has a reason for the size of gates used. He will maintain that there are innumerable reasons for a certain size gate which governs the pouring time. The plotting of the data of his gates clearly shows that the weight of casting is the important item. Regardless of whether the castings are plates, radiators with length from 17 to 45 inches, round boiler castings of various designs, or square boiler castings of plain and complicated designs, the time required to pour these castings lies very close to a definite line which we propose to call the pouring time curve.

A more detailed study of the pouring time curve shown in Fig. 1 may be made by considering only a part of the curve. In Fig. 2 is shown the pouring time curve for castings weighing less than 70 pounds. This weight would include the majority of our plate work and all radiators. If there is a definite relation between pouring time and weight, then the section of pouring curve Fig. 1 of large and mold castings, when plotted on a large scale for small castings, should take the form of Fig. 2. One may readily note that the curves of Fig. 1 and 2 are identical. In other words, it seems that one pouring curve will hold true for all casting weights.

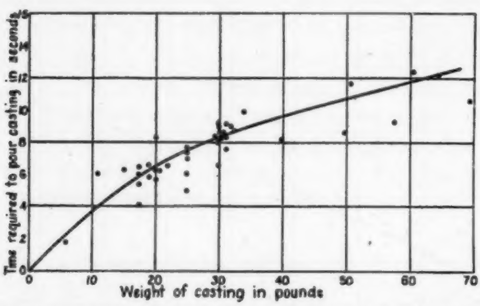

FIG. 2—POURING TIME CURVE FOR RADIATOR AND PLATE CASTINGS

The curve Fig. 1 shows that plain and cored castings were poured at the same time providing weights were identical.

The pouring curve (Figs. 1 and 2) is a parabola with an equation $y = \sqrt{2px}$. Substituting pouring time for y, weight of casting, for x and 1.25 for the constant 2p in the above equation, we have,

$$\text{Pouring time in second} = 1.25 \sqrt{w}$$

when w = weight of casting.

To calculate the pouring time of a casting knowing its weight, obtain the square root of weight and multiply by 1.25. For example, a casting weighs 400 pounds. The square root of 400 = 20. Then $20 \times 1.25 = 25$ seconds. The correct pouring time for a 400-pound casting is 25 seconds.

The pouring time of a casting may also be obtained from

the curve of Fig. 1. For example, a casting weighs 400 pounds. Find 400 on bottom scale of chart. Next trace the 400-pound line vertically until it intersects the curve. From the curve go horizontally to the scale at the side of chart. Note the number which is, in this example, 25 seconds. This is pouring time for a 400-pound casting.

Use of Pouring Time Data

The pouring time as calculated, or obtained from the chart, may be used in ascertaining whether the casting is poured too slow or too fast. Since the pouring time chart is a graphic presentation of actual foundry practice, any data obtained from it embody years of experimental gating. The use of the pouring time to check the gate size will thus eliminate much experimental gating by determining the size of gate which is the most desirable. Check the pouring time. If pouring time is too long decrease the size of gate, or increase the gate size if pouring is too slow. The chart also offers a means of comparing gates used in various molds.

Calculating Gate Size

The exact size of the gate required to run a pattern may be readily calculated. In this manner patterns may be equipped with proper size of gate before they are sent to the foundry, and when they are in the foundry they may be placed on production immediately without experimenting on the gate.

The pouring rate must first be determined before area of gate can be calculated. When the weight of a casting is divided by pouring time, we obtain a figure which represents the pounds of iron poured per second into the mold, or the rate of pouring.

The rate of pouring curve Fig. 3 is similar in form to pouring time curve Fig. 1. The pouring rate curve Fig. 3 shows that the rate at which a casting is poured depends upon the weight of casting. In this manner it agrees with pouring time. The rate of pouring curve Fig. 4 for radiators and plate work is identical to the pouring rate curve Fig. 3 for plate, radiators and round and square sections. This is a proof that the same principle of pouring holds true for this group of castings ranging from the smallest to 1,000 pounds in weight.

The formula for the rate of pouring is:

(a) Rate of pouring in pounds per second $= \frac{W}{1.25\sqrt{W}}$ or $.8\sqrt{W}$

(b) Rate of pouring in pounds per second $= \frac{W}{T}$ when $T =$ pouring time in seconds and $W =$ weight of casting in pounds.

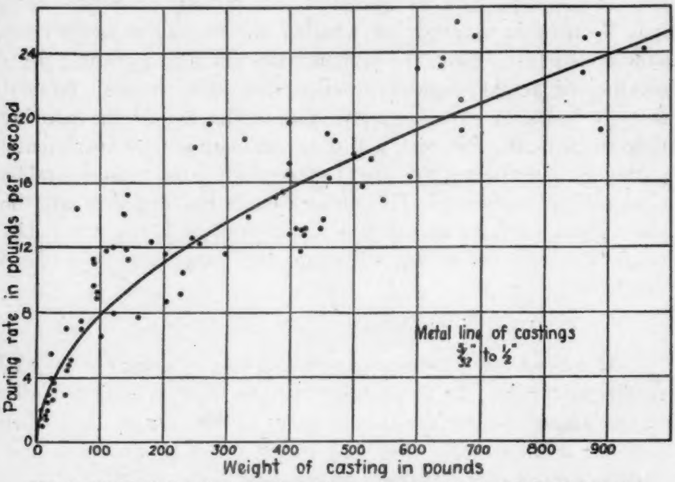

FIG. 3—POURING RATE CURVE FOR LARGE AND SMALL CASTINGS

A simple way to obtain the rate of pouring is to divide the weight of casting by pouring time, or formula (b). For all new patterns which have not been in the sand use formula (a) or use chart Fig. 3. This chart is used in same manner as described for chart Fig. 1.

After the pouring rate for the casting is obtained by one of the three methods, the area of gate required may be calculated as follows:

Area of gate in square inches $= \frac{R}{2.5\sqrt{h}}$ or $.32\frac{\sqrt{W}}{\sqrt{h}}$

Where

$R =$ Pouring rate in pounds per second.
$h =$ Effective height of sprue in inches.

Effective Sprue Heights

The area of gate required will depend upon weight of casting and ferrostatic pressure, or effective sprue height, for castings of a classified metal line. The greater the ferrostatic pressure, the

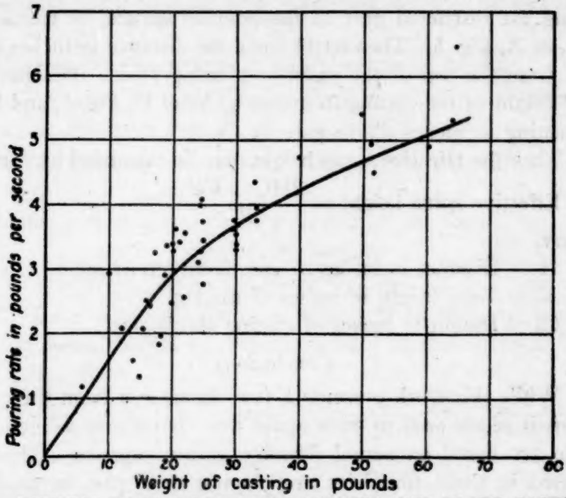

FIG. 4—POURING RATE CURVE FOR RADIATOR AND PLATE CASTINGS

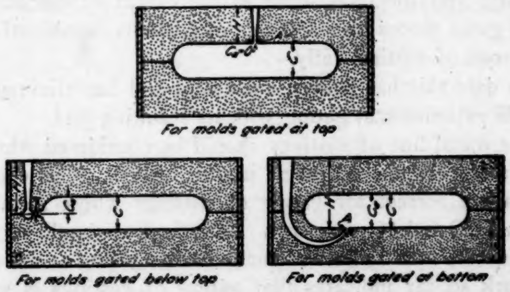

FIG. 5—DIAGRAMS OF MOLDS TO SHOW MEANING OF EFFECTIVE HEIGHT OF SPRUES

smaller will be the required gate. The ferrostatic pressure will diminish for molds gated at the bottom of mold as the iron level rises in the mold. This also applies to any molds gated below top

of mold. Under these conditions, a varying iron head or sprue height will exist. This requires that one use the average or effective sprue height for calculating area of gate. In Fig. 5 are shown cross sections of molds gated at bottom, top and parting line. The effective sprue height of any shaped mold may be calculated by calling the restricted part of the pouring spruce, or runner, the gate, as A, Fig. 5. Then let H equal the distance in inches of the gate from the top of the mold or pouring basin. Designate the total height of the casting in inches by letter C, Fig. 5, and height of casting in inches above gate by Ca.

Then the effective sprue height may be calculated by formula:

$$\text{Effective sprue height} = \frac{2HC - Ca^2}{2C}$$

Where,

H = Distance in inches of gate from top of mold.

C = Total height in inches of casting.

Ca = Height in inches of casting above gate.

Conclusions

While this work presents a few departures from the general belief, it seems well to state again that charts and deductions as made are based on actual foundry gating practice. The gates as used in these foundries are playing their part in producing castings at a very low loss. Much confidence has been placed in the charts and formulas, even to the extent of calculating the area of gates placed on a full line of patterns capable of producing 80 tons of casting daily.

To date this has proven successful and has eliminated considerable experimental gating with its resulting loss.

The metal line of castings should be considered when using charts and formula as given in this paper. The charts and formula are correct for gating of castings whose metal line is between 5/32 and ½ of an inch. Investigation should be made to determine the actual effect of metal line on gating of the castings. The work so far indicates that gating of castings is more dependent on weight of castings than the metal line.

Summary

1. A well defined parabola curve is secured when the pouring times, in seconds, of castings made in one or a group of foundries are plotted with reference to weight of castings.

2. The only item which influenced pouring time of the various sized castings, plain and cored, ranging from several pounds to 1,000 pounds, was weight.

3. A study of the comparison of the pouring time for various castings proved a means of reducing foundry loss.

4. The ideal pouring time of a casting may be calculated by the formula:

$$\text{Pouring time in seconds} = 1.25\sqrt{\text{weight of casting.}}$$

5. The ideal pouring time of castings may also be obtained from chart shown in Fig. 1.

6. The pouring rate of a casting may be calculated by the formula:

Pouring rate in pounds of iron poured per second =

$$\frac{\text{Weight of casting}}{1.25\sqrt{\text{weight of casting}}} \text{ or } .8\sqrt{W}$$

7. If the pouring time of a casting is known, the pouring rate may be calculated by dividing weight of casting by pouring time in second.

$$\text{Pouring rate in pounds per second} = \frac{\text{Weight of casting}}{\text{Pouring time in seconds}}$$

8. The area of a proper gate for a pattern may be calculated by formula:

$$\text{Area of gate in square inches} = \frac{\text{Pouring rate}}{2.5 \times \text{Sprue height in in.}}$$

$$\text{or } \frac{.32\sqrt{W}}{\sqrt{h}}$$

9. The effective sprue height h used in calculating gate

$$\text{area} = \frac{2HC - Ca^2}{2C}$$

10. The data as included in this paper have been used and found of practical value. They enable one to produce established foundry gating practice on a new or old pattern in a few minutes by simple calculations.

11. The results secured by the method outlined are identical to results produced by experienced foundrymen with the exception that the former is much faster and more certain at the start.

12. The charts and formula, as included in this paper, are correct for castings with a metal line of from 5/32 to ½ of an inch.

Written Discussion by S. M. Udale*

The chart as presented (Fig. 1) gives the diameter of sprue required for various weights of castings, when the diameter of sprue is used to restrict the flow of iron, under which condition it is the gate, as termed in Mr. Dietert's paper. On the left hand

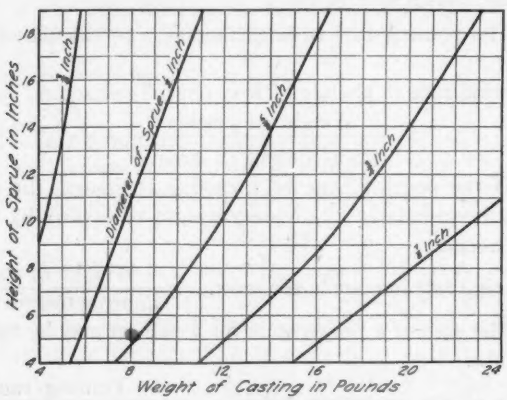

FIG. 1—CHART USED IN DETERMINING DIAMETER OF GATE

side of the chart is a scale for various heights of sprues. The height of sprue will partly determine the size of sprue when the sprue is the gate.

This chart is derived from formula, area of gate $= .33 \frac{\sqrt{W}}{\sqrt{H}}$.

The chart may be used to determine diameter of the gate as shown by the following example:

Let thickness of metal line of casting be between $\frac{5}{32}$ inch and ⅜ inch, its weight 11 pounds. When sprue height is 19 inches the diameter of gate or sprue required is ½ inch. When sprue height is 8.7 inch the diameter of sprue required is ⅝ inch.

*Holley Carburetor Co., Detroit, Mich.

What May Be Required of Malleable Cast Iron

By H. A. Schwartz,* Cleveland, O.

Since 1904 the tensile strength of malleable castings, as measured by the A. S. T. M. specifications, has increased from 40,000 pounds per square inch to 50,000 pounds per square inch, and the elongation from 5 per cent to 10 per cent. These changes were in large part motivated from within the malleable foundries, and it may be doubted whether the consuming interests did more than acquiesce in the acceptance of a superior material.

The economic desirability of these changes, irrespective of their cause, may be measured by the degree in which they increased the application of this product in the industries, or permitted a reduction in weight and hence of total cost of existing malleable articles. The author is not disposed to admit on *a priori* grounds that such economies did necessarily follow.

The inarticulateness of the consuming interests in this regard is regrettable, for a clear recognition by consumer and producer alike, of what properties are desired in a given product, is the first necessity of a satisfactory relationship. Sooner or later, the user's requirements find expression in the form of specifications, formally or tacitly understood, under which he orders, and accepts material. An inquiry into the consumer's demands may thus be both interesting and instructive as a basis for a study of what requirements should or should not be incorporated into specifications.

It would seem axiomatic that no requirement should be so incorporated which does not raise the useful value of the material more than its cost, for otherwise the product will, deservedly or not, fall into disuse.

It seems equally self evident that only such requirements should be included as are necessary, and sufficient for the description of the properties for which the material is used. Additional needless limitations increase cost without increasing value, and

*Manager of Research, The National Malleable and Steel Castings Co.

so violate the first principle laid down. Furthermore, it will be agreed, that any tests applied should measure, so far as possible, directly, the actual properties for which the material is valued, and that indirect tests should be employed only when accurately reproducible methods exist for direct measurement.

It will be readily granted that the calculation of the stresses in even a relatively simple casting, and under the simplest of load conditions, is beyond the limits of our present engineering knowledge. Consequently, no engineer is able to define upon a purely academic basis just what requirements will fit a theoretical material for an intended use.

Specifications can not, and should not be set up upon such a foundation. Their requirements are properly to be interpreted as a statement of the quality of a material known by experience to satisfactorily serve its purpose. They then serve as a means of determining whether other lots, purporting to be identical, are of equal quality.

What the Consumer Desires

Malleable castings are an article of manufacture because they possess a combination of strength, ductility, impact and fatigue resistance and machinability, which renders them more useful, cost considered, for certain purposes than their possible substitutes. With certain specialties as exceptions, the consumer desires to buy for a dollar the most he can get of each of these properties.

In what terms shall he describe his wants in order that, upon closing a contract, he may be assured that his minimum expectations will be realized?

He requires assurance that:

The metal, as cast, is of a quality yielding satisfactory physical properties upon anneal.

That each casting is completely annealed.

That each casting is sufficiently sound, mechanically.

From the very fundamentals of malleable metallurgy, these three factors are entirely separate and distinct.

The first is a question involving the individual melting furnace heat as a unit.

The second involves the annealing furnace heat as a unit, and implies a knowledge of the uniformity of heat treatment, throughout a given furnace. This is, perhaps, obtainable only by inspection of individual castings.

Soundness of Castings a Question of Foundry Practice

The third factor is not a question of *metallurgy,* or properties of materials, but of foundry practice.

The logical manner of controlling the first variable is by suitable mechanical tests, on a properly annealed specimen from each heat. The second by visual inspection of test lugs from each casting, if these be of fair size. The third by inspection of broken castings, or perhaps, in extremely critical cases, by X-ray examination of finished castings.

It is to be remembered that the form and preparation of the test specimen is just as much an essential of a specification as the required values of the physical constants to be measured. Test specimens are purposely prescribed of forms which can be produced with the greatest freedom from mechanical defects. The purpose is to eliminate as variables, all factors except the quality of the metal.

It is not implied in any specification that specimens cut in various ways from masses of material shall be expected to conform to the same standards. With the exception of rolled rods of small cross section, where, from the nature of the case, specimens can be produced with only one location and orientation with respect to the material, it will never be found that the strength of a metallic test bar is independent of the size and location of the test specimen in relation to the object from which it was cut.

The consumer who cuts a specimen from a casting and finds its properties inferior to the requirements of a specification such as that of the A. S. T. M. has not necessarily any cause for complaint, as to the properties of the metal. He may have legitimate grounds for objecting to the soundness, or integrity, of the casting if a harmful shrink is disclosed as the cause of failure,

or it may be that the casting is of such size and form that the unit stresses to be expected in the normal specimen can not be equalled. A lack of understanding of these principles is a frequent cause of unjustifiable complaints by the consuming interests.

It is wisely permitted by the present standard specifications that metal rejected as apparently "under-annealed" may be reheat-treated. This follows quite logically from the fact that the metallurgy of the product is a two stage process. While there exist certain broad and definite general relations between the two steps, it would be manifestly unfair to condemn the entire material for a remediable error in the second of the two steps.

How Shall Consumer Describe the Metal Desired?

We are now confronted with the major question of this paper. In what terms shall the consumer describe the metal of which his castings are made, in order that he will secure the most economical combination of the previously enumerated desiderata at reasonable cost and in reasonable time?

It seems self evident that the use of chemical specifications for a material of engineering construction is not justifiable where the desired properties can be measured and defined. Excluding the very limited applications of ferrous material under circumstances where their chemical behaviour determines their suitability for an intended use, there seems very little reason for writing a chemical specification. With very few exceptions, probably fewer than usually realized, the properties demanded of a metal can be accurately described in physical rather than chemical terms.

Importance of Physical Requirements

Chemical specifications are very generally meaningless. For example, pre war specifications for steel products commonly set a maximum sulphur content of .05 of a per cent. Extended investigation, motivated by war necessities, has failed to disclose, for most purposes, any decided superiority of such material over an otherwise correct metal containing .06 of a per cent sulphur. Why then, should the nation's industries be burdened with the expense involved in a reduction of the sulphur to the lower limit?

It is the author's carefully considered judgment that there is no defect in the metallurgy of malleable cast iron, against which the consuming interests can not more adequately guard themselves by physical rather than chemical requirements.

Chemical composition is the chief corner stone of works' control, and a knowledge of the chemistry of his processes and products the most useful guide at the command of the producer. The consumer, however, being of necessity not a specialist in any given raw material, is less likely to be sufficiently informed along these lines.

For example, a large and highly reputable automobile manufacturer has included in his specifications for malleable castings, a *minimum* carbon content. It is known to all of us that the strength and ductility of malleable cast iron vary inversely as the carbon content. Leaving aside the fact that the consumer's *minimum* value comes perilously close to making it impossible to secure his requirements with respect to tensile strength, his chemical requirement operates to reduce the quality of material which may be furnished him under his specifications, by limiting the quality of material which is admissible thereunder.

The author has not had the advantage of personal discussion with those responsible for this requirement, but is entirely unable to see what advantage the consumer believes he is securing under this specification.

The suggestion was once made, unfortunately by a producer, that a suitable limitation upon the carbon plus silicon would assure the user against "low", that is, primarily graphitic iron. This argument is fallacious, because it ignores a multitude of other factors, influencing primary graphitization, and inexpedient, since freedom from "mottles" can be much more easily guarded against by direct inspection of hard iron castings than by complex argument applied to the results of time consuming analyses.

Quantitative Description of Physical Properties

We are left, then, with the opportunity of describing quantitatively the physical properties required in a casting. Theoretically, it should be possible to describe, in quantitative terms, all the properties desired in the material to be used for a given

purpose. Practically, this is but a vision and far beyond the limitations set by our present engineering knowledge, both with respect to testing, and design.

Even if sufficient knowledge were secured, the execution of a multiplicity of tests would be so wasteful of time and money as to be economically unsound. The problem is then to select one, or at most, a few tests, simple and accurate of execution, which may be considered a measure of the conformity of the product to an established standard. The tensile properties of materials have come to be adapted very generally for this purpose, largely because of the relative simplicity of their determination.

Possible Tests

Many engineers have expressed themselves as being uninterested in the tensile strength of the metal in the malleable castings they buy. Strictly speaking, this attitude is justifiable, although they probably are interested in many other properties which are found in metal of satisfactory tensile properties. It is however, incontrovertible that tests regarding the behaviour of malleable castings under fatigue or impact would form a much more direct measure of the materials' utility than do static tension tests. The same may be said of any other materials to be used in machine parts or elsewhere, under conditions of variable load.

Tests of this character have not, as yet, been standardized sufficiently to commend them generally as a basis for the acceptance or rejection of a material. They may, however, be expected to grow in favor as they become better understood. It is by no means unlikely that some form of impact test, such as the Charpy, may come into more extended use for various materials in the reasonably near future.

The Walker wedge test, constituted an attempt in this general direction. It found but little permanent favor because it became evident that the test was not strictly reproducible. This is a criticism of this particular form of test, and of the apparatus for its execution. A sufficiently simple impact test, capable of accurate reproduction, might prove to have great utility.

Cross bending tests, once demanded by the standard specifications, have been very wisely omitted in recent years in this country. They had proved entirely superfluous, since all metal capable of passing the then existing tensile requirements passed them so easily that those tests added nothing to the user's knowledge of his material. With characteristic practicality the British still require, on white heart malleable, a bending test as a measure of the deformation the material will undergo, and not as a strength test.

Tensile tests required on malleable have, so far, included only a requirement for ultimate strength and elongation. They are certainly as good measures of this material's fitness for an intended use, as of the utility of a steel casting or forging. Whether or not the values now set for these constants, namely 50,000 pounds per square inch and 10 per cent elongation, are the most desirable remains an open question.

An increased strength requirement, accompanied by a suitably increased elongation, will certainly be accompanied by an increased resistance to fatigue, and impact. It will be shown later, that where machinability is important, a balance must be struck between the value of strength and ease of cutting, and an indefinite increase in strength is, therefore, not necessarily in the user's interest.

During the last year or two there has come, from some sources, a demand for the inclusion of a figure for yield point in the tensile specification. The demand has behind it a measure of logic, since most ferrous materials are being specified from this viewpoint, or at least have been studied by engineers sufficiently, so that the user is satisfied that he can rely upon a given yield point from a known kind of material, of given tensile strength. It is also obvious the yield point rather than the tensile strength is the limiting factor, in the design of static structures at least, while the fatigue limit is the true criterion under dynamic conditions. Fortunately, the latter is nearly uniformly 50 per cent of the ultimate strngth in all ferrous materials so far tested. It was, therefore, inevitable that the user should demand either a guaranteed yield point, or at any rate, some definite assurance of the relation of yield point to ultimate strength.

As a mere expression of the author's opinion, it may be here stated that the yield point of malleable cast iron is certainly above 60 per cent of its ultimate strength.

Its exact location may, however, well be a subject for argument to a much greater degree than in the case of competitive materials. Having recently made a critical study of data from seven laboratories, including two consumers, one consultant, and four producers, one not connected with the same corporation as the author, it has been conclusively shown that different experimenters will vary as much as 4000 pounds per square inch or about 12½ per cent of the mean value, in the average results of long series of tests for this constant on metal of equal quality. Such a lack of agreement is obviously disquieting.

The cause of this discrepancy is not difficult to find. If one examines the tensile stress-strain diagram of any commercial structural steel, and compares it with a similar diagram for malleable cast iron, it will be quite noticeable that the former shows a very sharp discontinuity at the yield point, and frequently an actual decrease of stress for a brief interval, while the latter shows only a uniformly increasing rate of curvature. It is, therefore, obvious that there is no stress at which the strain in malleable castings increases without increment of stress, and the location of the yield point becomes a matter of definition. We may, for example, say that the load at which the specimen has elongated ½ per cent (0.01 inch in 2 inches) should be regarded as this point. This is approximately the point determined by the divider method. Alternatively, we may define the yield point by the slope of the stress-strain diagram, and define it as the point at which strain increases with stress at a given rate; for example, by 1 per cent, for an increase of load of 5000 pounds per square inch.

The latter definition gives results substantially interchangeable with the former, but is not feasible as a basis for a specification, because it requires the somewhat laborious construction of a stress-strain diagram for each specimen.

The Yield Point

At present, the yield point is frequently defined as the point where "the beam drops" in testing. The incongruous data al-

ready alluded to, were obtained in this way. In the author's judgment, this method has little but simplicity in its favor. The reason for the non concordant results are as follows:

(1) The absence of any point which stress does not increase at all with the strain renders the point indefinite, *per se.*

(2) The specimen, being unmachined, is not of uniform cross section, throughout its length, hence different zones reach the yield point at different times, and render the point even vaguer.

(3) The specimen being held by wedge grips, is not definitely located with respect to the cross heads of the machine, and slips in the holding mechanism may confuse the yield point or be mistaken for it.

(4) The specimen, being never perfectly straight, introduces similar errors.

The investigation just alluded to indicated that a given increment of ultimate strength produces substantially the same increment in yield point, irrespective of the circumstances of manufacture of testing, but that the absolute value of the yield point for a given ultimate strength will vary materially both according to the origin of the material and the observer.

It may not be inappropriate to point here to another instance in which in the past, the drawing of an analogy between malleable cast iron and steel came perilously close to causing confusion. It is not unusual in steel practice, to define the required elongation in the steel in terms of the reciprocal of its ultimate strength, or vice versa. Thus it may be required that the elongation shall at least equal a prescribed constant, divided by the ultimate strength. A similar proposal was once made to one of the A. S. T. M. committees engaged in one of the earlier revisions of that society's malleable specifications.

It is well known that in the latter product the elongation increases with tensile strength, and a great strength coupled with lowered elongation is an evidence of incomplete graphitization. A reciprocal relation, as in steel, although apparently desirable from the viewpoint of analogy, would have been worse than meaningless, for at only one strength could malleable have had any given specified relation.

Formulæ have been proposed for calculating a so-called "Allowable Working Stress" in terms of yield point and elongation. It is true that the yield point and elongation of quite high class malleable cast iron is such as to yield calculated allowable stresses, equal to those in grade "A" steel castings.

These facts furnish a theoretical foundation for the belief that such extra quality material defined by specification, in terms of calculated working stress, may be substituted on equal terms with the corresponding steel castings. The author is not sufficiently familiar with the derivation of the empirical formula for allowable stress to warrant an expression of opinion of the *a priori* validity of this conclusion. He, nevertheless, believes it to be correct, but finds substantiation for this belief in the known behaviour in service of the metals rather than in the agreement as to working stresses.

It is true, that no specific values of ultimate strength and elongation may be referred to in writing such a formula. The unavoidable relationship of the ultimate strength, yield point, and elongation are such that a malleable of the same calculated allowable working strength as grade "A" steel will, of necessity, have a considerably higher elongation and somewhat higher ultimate strength than the minimum now acceptable. Such a specification, will, therefore, be equivalent to an increase in the required tensile properties, and while metallurgically possible, may or may not be desirable, depending upon whether the utility of the material is thereby increased sufficiently to compensate for increased difficulties in other directions.

It has already been pointed out that an increase in tensile properties involves also an increase in all the other properties required of the material in use. This can not be said, however, of the properties valued during fabrication.

Malleable cast iron is used for some purposes, where it is never stressed anywhere near its safe limit, merely because it is the most machinable commercial ferrous material, possessing any useful degree of ductility. A consumer of castings of this type will not find his interests served by any increase in the specified strength requirements.

Machinability Requirements

Machinability requirements are already at least implied in many agreements, and consumers consider themselves justified in rejecting material defective from this viewpoint. Very unfortunately, there is not yet any satisfactory means of describing quantitatively, the degree of machinability any given consumer may consider indispensable. If there were, it might be possible to evaluate the relative importance of strength and machinability, and set up a specification consistent with the best interests of consumers whose major purpose is to attain economy in fabrication rather than a given strength standard.

The writer has shown elsewhere, that the cutting resistance of malleable increases with its strength, and it can therefore, be safely said that an increase in strength involves some increase in machining difficulty. Whether this increase will be noticeable to the consumer depends altogether upon his own shop methods, and which horn of the dilemma he prefers is a matter altogether of his own engineering practice. The choice obviously is determined by whether an increase in strength is worth more than any increased manufacturing cost which may have to be incurred.

In the absence of any means of writing an exact specification for machinability, it is frequently difficult to determine whether or not a given material possesses a normal cutting resistance, and still more difficult for the consumer to assure himself of the satisfactoriness of a given shipment.

Under the usual metallurgical conditions, an increased resistance to cutting may arise from several causes:

(1) Perfectly normal malleable of such ductility and strength as to be inherently difficult to machine.

(2) So called "picture frame" iron which has a steely surface, difficult to cut, but is normal within.

(3) Iron which has a very wide decarburized rim, which is not hard, but tough, and hence machines slowly.

(4) Iron which is pearlitic throughout, or, in extreme cases, may approach the original hard iron in micro-structure.

The second and fourth difficulties can be entirely guarded against if the customer will inspect test lugs left on the casting, for that purpose, and reject those which have the readily recog-

nized fractures characteristic of these difficulties. Such castings can frequently be perfectly reclaimed by an appropriate heat treatment. The latter fault is almost always due to pure accident, very rarely representing a metallurgical defect of a great bulk of castings.

The first cause is actually not a defect, but represents merely the selection of the wrong grade of material for a given purpose. Incidentally, it may be said that trouble from this source will occur only where machining rates are already crowded to the limit.

The second defect is very difficult of recognition, except by the metallographer, and neither it nor the first is readily detected by test lugs. Hardness tests of the usual types are utterly useless. Only the fourth condition would be recognized by such test, and it is more easily found by test lug inspection.

There is in no case any definite relation between cutting and indentation hardness sufficiently marked to use the latter as a measure of the former. Losses from the destruction of tools are almost invariably due to the second and fourth causes, the other two, at most, setting a limit to cutting speeds.

A major commercial problem is to deal equitably with the condition existing when there are delivered to the consumer a great number of satisfactory castings through which a few of inferior machinability are scattered without any means of finding the latter. A very few hard castings will entirely disorganize a day's production schedule by the breaking of tools. To this extent, they work an injury on the user out of all proportion to their number. On the other hand, it is distinctly unfair to the producer to return to him a carload of castings which may be all good except one or two which have given trouble.

It is under such circumstances as these that test lug inspection by the consumer will work wonders by enabling him to check the castings before delivery to the machines and relieving the producer from the sole responsibility of seeing that not a single poor casting ever goes on with those which are acceptable.

Welded Castings

The subject of the welded casting is very closely associated with that of machinability. It is probably quite generally ad-

mitted that defects involving a reduction of strength in critical parts should never be repaired by welding. An extension of this principle to all defects is not economically sound.

Many surface imperfections can be perfectly repaired by a welding operation with a consequent saving due to decreased foundry losses, and without risk of inferior service to the consumer. Such welds can be made identical in every respect with the surrounding metal, if necessary.

Welds made with white cast iron filler rod and subsequently annealed are undetectable unless accompanied by a visible defect of workmanship, and would be admissible for any purpose if assurance could be had of their subsurface soundness. It is a very great injustice to reject all welds because improperly made welds are usually difficult of subsequent machining.

Some Consumers' Requirements Illogical

Lastly, the author would allude to practices on the part of consuming interests which seem to him highly illogical. Why do some consumers want to buy a high grade metal without being in any degree interested in the mechanical soundness of the casting as a whole? Why do other consumers insist on mechanical soundness in places, and under conditions where a failure of the part is unthinkable? Why are cast parts so frequently designed by persons entirely unfamiliar with foundry problems and without that consultation with foundrymen which would eliminate many difficulties? Why should so many producers insist on early deliveries to an extent which makes it virtually impossible for the foundryman to give adequate time and attention to their requirements?

Self interest would seem to dictate to buyers a policy of eliminating serious and important defects in the interests of satisfactory use, while ignoring, in the interest of economy, technical flaws which are without effect in the intended use of the product. Similarly, the user should certainly be as much interested in making it as easy as possible to secure the best results under given conditions as is the producer.

The tendency of a manufacturer to reduce his stock of material in process is most laudable as a means of economy. Very

naturally, therefore, he strives for early delivery from his source of supply. On a perfectly standardized article, the producer of the semi-finished product can meet this demand by carrying a stock for the consumer. No overall economy results, however, for the same amount of capital is still invested in inventories, the producer merely acting as a banker, with or without adequate return, for the consumer. Even this course is generally not open to the jobbing foundryman who may have no assurance that any castings made up ahead will ever be required.

On work from patterns previously used by a given foundry, the greatest time consumption in the manufacture of malleable castings is in the annealing operation. The subject of the possible commercial reduction in annealing time has probably been discussed sufficiently before this Association. The present status of this matter seems to the author as follows:

Heat Treatment

Nothing has appeared in recent years which suggests to the progressive malleable foundryman any useful changes in regard to his heat treatments.

Engineering improvements in furnace design, the tunnel kiln for example, which make for greater uniformity of temperature, and its better control, which reduce the overall time by reducing the time spent in heating and cooling. So long as castings must, for economic reasons, be handled in bulk, their own heat capacity sets commercial limits upon these rates. The actual temperature cycles of many foundrymen are already as efficient as they can be made within the present limits of furnace design and stock heat capacity. The problem of reduction of annealing time is thus almost altogether that of finding chemical or other conditions under which the process of graphitization can be accelerated without undue detriment to quality or cost of product. The possibilities of temperature in this direction have been practically almost exhausted.

Question of Chemical Composition

The question of chemical composition with respect to the usual elements, while admitting of further quantitative study, is

qualitatively well understood by many, and revolutionary changes are not to be anticipated. Whether careful study of other elements of composition, or other but vaguely suspected variables, will result in commercial improvements must await the event. It must be remembered that, to be industrially valuable, a process must be both metallurgically and economically workable.

In cases where new patterns are to be made, experimentation as to the most economic methods of manufacture or the best means of securing adequate soundness of casting must be taken into consideration. Castings made without such study, from new equipment, are very likely to be inferior.

Finally, it should be remembered that over an extended period of time, the buyer will pay for all he gets and the seller will give value received. There are perfectly good reasons why Detroit's leading citizen does not sell Lincoln and Ford cars in competition with each other.

Discussion

E. Touceda: I might start the discussion. Professor Schwartz, I think you have misquoted Dr. Dudley. I do not think that he said there should be any chemical limitations in a specification. What he desired to avoid was to specify both carbon and physical qualities, due to the danger of incompatibility, but he never inferred that there should be no limit on phosphorus or sulphur. If you are going to specify physical properties, it is permissible and better to leave the carbon off. I cannot let go unchallenged what you have stated in regard to the determination of the yield point. We feel positive that we can get the yield point very accurately, and I am going to tell you what we have done of late in that particular. Lately we have been testing quite a number of bars, something like six hundred of them, and have found no difficulty with the drop of the beam test. I personally have taken the yield points on perhaps eighty or ninety per cent of the number. When the first prick punch is made it is extremely minute. In making the test by the divider method we use a reading glass in order to determine when the first diviation occurs. In other words, we exercise all the precaution we can to get an accurate yield point by the divider method, but we find that we can get just as close by drop of the beam as by the divider method. I want to go on record as far as we are concerned in stating that we think we can get the yield point by drop of the beam within a very close degree of accuracy. If you are going to make such tests, it is essential you

should be prepared to make them. You have stated, Mr. Schwartz, that in a recent study you have found a big discrepancy in various mechanical properties in bars cast from the same mold. I would point out that if you are going to test out the accuracy of one testing machine against another and have no special apparatus for the purpose, it is possible to take a long steel bar and cut it in 15 parts, numbering them, one, two, three—up to fifteen, and by one party testing the even numbers and the other the odd, the average results on each lot will yield a fair comparison, but in comparing individual tests together considerable disparity will be found. If you will find an unevenness in the same bar of steel which is a worked product, it is not strange that two castings from the same mold that are tested as cast and which have not been worked should be somewhat dissimilar in mechanical properties.

In your reference to the causes that interfere with good machining properties you have absolutely omitted a consideration of shrink. We think the matter of shrink is a much more important consideration than any other factor you have mentioned as far as machinability is concerned. Not only internal shrink, but surface shrink, the microscope showing certain surface imperfection to be structurally like a shrink. It does not make any difference whether inherent unsoundness is due to shrink or some other cause that produces porosity. We have observed that under certain conditions when iron enters a mold, there will be disturbances at the surface sufficient to cause a porosity that structurally will be like an internal shrink. Such porosity as will cause the development of free cementite and to all purposes is just exactly like internal shrink. I can easily show you a number of photographs in which surface shrink is shown.

In regard to machinability I will say this: In the course of a year we probably received seventy or eighty samples from the members of the Association. We have never received one whose cutting hardness we could attribute to composition of the material. Nearly all were due to shrink, or due to a framed condition. Occasionally one might find one hard all the way through, due to the fact that it was not properly annealed, but we have failed to find any that were hard due to composition.

Another thing, Mr. Schwartz, in your discussion of your tests on machining, you speak of the load being proportional, the work on the tool being proportional to the ultimate strength. Was the tool lubricated?

H. A. Schwartz: No.

E. Touceda: There is where I think you will find some trouble. We know that the best lubricant for threading is lard oil. I am just speaking of this to bring out the importance of lubrication. We have had a great deal of experience in connection with this matter for a period of some twenty years with New England manufacturers, and we know and they have found that the best lubricant in threading is lard oil. When

the lard oil is adulterated or an inferior oil used, the temperature rises. I do not think there is anything else that I have made note of. I think you have presented a very commendable paper. There is a whole lot of meat to it, but it would take a long time to discuss it all.

H. A. SCHWARTZ: What I have to say, I wanted to say in the beginning. I am not arguing whether the Malleable Association's figures on yield point are right. What I say is not criticism. I want that perfectly and definitely understood. Professor Touceda refers to uniformity of metal. These comparisons were made on say twenty or thirty heats by comparing tests made in the different laboratories. I do not know why it is, but I do know two laboratories can get four or five thousand points' difference on the yield point. I do know as a matter of fact that if you take a considerable number of heats in which presumably, after you test quite a number of bars, the mechanical flaws should balance; have Mr. Touceda test them, I test them and Mr. Bean test them, and the result of the different laboratories will not come out consistently. I am holding no brief for any particular way to make the test. My only argument is that testing engineers in general do not do it, and do it alike, in the sense of getting concordant results. If we take twenty heats from our Toledo or Chicago works, and take the Association's results on those, and our own records, or if we take a series of two tests from our own laboratories on machines which have been calibrated, and we get different results, my argument is that there is need of criticism on the determination of yield point as a method of testing the material. I grant the necessity of measuring yield points, and grant the absurdity of measuring elastic limit. My criticism is irrespective of the experience of Mr. Touceda in his laboratory, granting that his results are perfect, then the other fellow is imperfect, but we may have to guide ourselves by the other fellow's tests. So long as we get such variations, we feel we are in grave danger in introducing yield point specifications. I want to repeat now what I said in the beginning, that I have no criticism nor any suggestion as to how the Malleable Association's results may be improved upon, but, unfortunately, I am in the same position as others in that on a fairly large scale of comparisons there are differences between our results and theirs.

With respect to machining tests, you can talk all day on that. We had to limit ourselves to the pretty simple kinds of tests. I think it has been pretty well shown that the life of cutting tools is in proportion to the temperature with which they work. The actual test is to see how high a production can be had on castings.

I am not prepared to grant offhand that the inherent quality of material never affects machinability. The surface shrink which Mr. Touceda speaks of, I have omitted because I have not seen any of them. If there are surface shrinks, I think it would have the effect that Mr. Touceda stated. I think I stated, at least I meant to say that in regard to

Dudley's argument that we should not specify both chemical composition and physical property, the phosphorous determination constitutes an exception.

E. Touceda: I really feel that in the case of carbon steel you will never come to the point where you can possibly eliminate all chemical requirements, while in the case of alloy steels you have to designate them. In the case of rails, we know if you have manganese up to a certain point with certain carbons, you are all right. If you transgress then you may be in a serious fix.

F. M. Robbins: I am very sorry I didn't receive a copy of this prior to last night, as it is one of the most excellent papers on malleable iron I have ever had the pleasure to read. As a matter of fact, I think each one of these subdivisions of the paper might well be assigned to some separate committee for attention of discussion, which I trust will go on because there are so many items here of so vital an interest to industry. I am sincere in my statement that I think they should be carried on, because Mr. Schwartz, I believe, conscientiously and intentionally pointed out the number of points which this body could do in order to carry on to greater limits. Some of these have been brought out by Professor Touceda, and I hope others will be brought up. I would like to hear some discussion on the basic principle underlying the paper which Mr. Schwartz stated in his oral presentation, that is, the question as to whether or not in order to meet what might be termed a market condition, attention should be given to the reduction of specifications. Knowing as I do Mr. Schwartz over a number of years, and that his nature is to increase those specifications, and increase the quality of malleable iron which is produced in this country, I can only believe, of course, that this is done with the view to bring out constructive criticism and unity of thought on the subject of specifications. The malleable industry having attained the position where it is today, as regards quality and soundness in material, furnished by intensive effort, it seems the real vital question, if we should at this time consider the reduction of the specifications with the possibility of retrograding to a point where industry was ten years ago. It has been a great deal of work to build up the industry in the country. To meet the demands of some irrespective of quality and reduce that specification in order to enable them to save a few pennies, what would be the effect of that upon us as malleable manufacturers, ultimately. Are those castings which are made under certain specifications to be so controlled they will only reach the manufacturer who does not care what the quality product may be? I think that is a vital subject of discussion.

W. R. Bean: To save time, I want to second all that Mr. Robbins has said. I feel there is a great deal to be accomplished. There are one or two points I wish to comment on in Mr. Schwartz's paper. If I remember correctly, wherever the yield point is specified in a ferritic material, the method by which that is to be determined is also specified,

and so long as that is so, it seems to me we are fairly safe in including a yield point specification for malleable iron. The latest specifications I have seen for steel all call for the drop of the beam method. That is the simplest method that I know of.

We have been conducting the yield point tests on all heats produced in our plants for nearly ten years. The machine we use has an automatic poise travel. We have studied these during that time in anticipation of a demand for the inclusion of that test. We do not get uniformity of results, but neither do we get uniformity of results in ultimate strength. I have no figures definitely in mind. I didn't see Mr. Schwartz's paper until yesterday, so I was not able to look up our records, or make up any absolute comparisons as to whether there is a greater variation in yield points than there is in the ultimate strength. I think there is. I think in ultimate strength there is a much more definite point than is possible for the yield point. We have made comparisons between the divider method and the drop of the beam method. We got a somewhat higher result from the drop of the beam, taking the average figures from a considerable number of bars. We prefer not to take just companion bars, but in most of our work, aside from routine, we take the average of a number in each case. Now, I cannot see that so long as the method of test is just as definitely fixed as the result of that test, there is any grave danger from a yield point figure in the malleable specification. Competitive materials employ it. I understand this whole question has come up as a result of the desire or the necessity for the malleable industry to become more definite in competition with other materials. That seems to be the purpose of the discussion. It seems logical that the malleable industry should fall into line and provide this test along the line with other tests.

On the question of machinability, we have worked for ten years to find a simple and satisfactory method for the determination of that property or characteristic of malleable iron. We haven't been able to get very far. Our customers are more particular in that respect than the majority of the malleable producers. We produce a great deal of tonnage that is threaded, and that is the most difficult operation to perform on a malleable casting.

We find, as Mr. Schwartz pointed out, that the greater part of the trouble comes from abnormalties in composition or anneal. We have found a number of instances of surface shrink. We have had a good many instances of that difficulty in machining.

One point not touched upon, which for us is very important, is decarburization. It seems to us to make more difference whether a casting has been lightly or highly decarburized during annealing than whether it was 2.20 per cent or 2.70 per cent carbon in the original hard iron. That would have little or no effect on a drilling operation. It would have less effect on a lathe or boring operation. The results are directly proportional

to the amount of carbon that is left in the metal that has been annealed. At least that seems to be our experience in that particular proposition.

E. D. Halsey: With reference to the machinability on castings, my theory is taken from observation, and back when we had lower specifications we had less rejections. The automotive industry has increased production, speeded up production, and it seems to me we would not accomplish anything going back to the earlier specification.

Porter Spencer: Professor Touceda and Mr. Bean have referred to the surface shrink. I am wondering whether a little more light on that subject might be interesting here. Does this surface shrink have any characteristic of a dendrite?

W. R. Bean: I don't know that there is any agitation on the question of a lower malleable specification. I do believe, however, in view of the desire of some of the producers to have an increased specification for certain classes of work, where strength is demanded, more than a single specification might well be considered, a specification which is adequate to protect the user of castings of light section, where strength is not a primary factor, and the higher specification to protect and safeguard the user of castings requiring greater strength. The steel specifications are so drawn. There are several grades of steel, and it would seem just as logical to have more than a single specification for malleable iron.

Chairman L. C. Wilson: Referring to Mr. Spencer's question. I believe Professor Touceda can answer that.

E. Touceda: I think it is a question of a local disturbance of metal in the mold. You know on flat surfaces how hard it is to have metal lay quiet. It is the same on other surfaces also. If there is anything that interferes with the quiet flow of the metal, like too much water, etc., the condition referred to will be produced. If you take the cope off a mold you will see all kinds of agitation. Such disturbances produce what we call a surface shrink. I tried to make it clear in the discussion at the time that under the microscope it will be exactly like a shrink, that is, it has all the earmarks of a shrink. You do not need the microscope to discover it, all you have to do is machine the casting, the surface of which will look like it had eczema or some other disease.

E. M. Handley: I have watched that for a long time. I would call it slag. It is caused, as Mr. Touceda says, by striking a hard spot in the mold. You will generally find that it appears in the corners or on the top somewhere.

C. H. Burgston: There are several things I would like to mention from the operating viewpoint. We have made quite a number of tests on the yield point, and I think I have to agree with Mr. Schwartz. We find

it rather difficult to take hold of. Both our laboratory and our general laboratory have had difficulty at all times in checking malleables. As I see this proposition, it may be that the divider method is satisfactory, and the method of noting the drop of the beam method is satisfactory, but I believe this body should arrive at some definite and tentative method of tests. I know cases where a series of bars from the same heat, annealed under identical conditions, have shown yield points from twenty-seven thousand up to thirty-five thousand. There is just one thing I would like to mention here along the line of surface shrinks or hard checks as we call them in the foundry. I don't think there is a foundry condition that causes more trouble and more loss today than the subject of shrinks and hard checks in castings. I believe the committee of the American Foundrymen's Association would do well to make an intensive study of the causes of hard checks.

D. M. Scott: I would like to go back to almost the first part of Mr. Schwartz' paper, where, I believe in the second paragraph he states he does not personally know of cases where the design has been made by reducing the weight through the increase of physical progress. Do I get that right?

H. W. Schwartz: The economic desirability of these changes, irrespective of their cause, may be measured by the degree in which they increased the application of this product in the industries, or permitted a reduction in weight, and hence of total cost of existing malleable articles.

D. M. Scott: I take issue with that.

H. A. Schwartz: Did they follow it because the materials are better or the men got more intelligent?

D. M. Scott: The reduction in weight could not have been made except by the improved value of the material. I just wonder whether the sequence would be wrong as you bring it up. In other words, should we wait for the customer to require a high and elastic limit, high elongation before we furnish it? You are absolutely correct when you say an engineer cannot calculate the stresses and make his design to suit the tests which castings will be subjected to in service, but they make their changes as they get experience with failures of castings. Then after all, the manufacturer of malleable iron must protect the reputation of the product regardless of whether we get a sufficient price or not, and unless we make our product sufficiently high value, where we do not get a large number of failures, we would not have any foundries to produce it. What I am driving at is, I am absolutely in favor of bringing the specifications to the point where we know we can meet the occasion. The present specifications are certainly low. As I gathered in the discussion, we are holding specifications low so as to save maybe one heat of malleable iron out of two or three thousand. I don't think that is fair to the consumers of

malleable iron. It certainly is not going to increase the consumption a whole lot.

H. . SCHWARTZ: I think I spoke advisedly when I came to the conclusion that nobody is using malleable castings now that did not buy them before the specifications were raised to their present value. Most of the things made of present day malleable are so strong you could not break them. The manufacturing process sets your limit on how thin you can make them. Increased physical properties will hardly let you lighten the casting. Malleable transmission cases were at one time very common. In the time when they were in favor in competition with gray iron and aluminum, I happened to be in position to inquire whether there were any failures on gray iron transmission cases. I was told that on a particular car as sold in Cleveland the distributor had never sold a replacement gray iron transmission case. If that is true, what is the object of making it of any higher quality of material?

In the last analysis you have to sell a customer what he wants. If the customer wants to buy a high quality product, you have got to make it and sell it to him. I know some people who order castings say they do not want high ultimate strength. If you do not give the man what he wants to buy and pay for, the result will be you will not have the customer, and therefore, no business. If it is inferred I am asking for a reduction in specifications, I am not. I am not arguing on either side of the fence. I am asking that we find out what the customer wants and is willing to pay for, and give it to him, and if it is fifty-five thousand pound iron, and we can make it, give it to him. I hold no brief for or against ten per cent elongation. When Mr. Scott refers to average values, do not forget when you use the prevailing average value of a physical property as a basis for a specification you condemn fifty per cent of your product.

MR. BUTLER: As chairman of the Committee A-7 of the American Society for Testing Materials, I was requested last year to find out to what extent specifications were really used. The reply from members of this committee indicated that specifications were not used by the consumer on over fifty per cent of the material that was produced in the different foundries. The question also came up as to the advisability of changing or increasing somewhat the standards of malleable iron in this committee. I think Mr. Touceda said he felt quite certain that all members of the association were against any change or increase in the values of physical property. I presume also that the co-operation of the American Society for Testing Materials will ultimately result in one specification. If anything can be developed from this discussion that would help my committee in any way in arriving at something it would be very welcome, I assure you.

A. M. FULTON: Just one point I want to ask. How do you overcome some of the surface cracks?

E. Touceda: The only way I know is to take care of your sand heaps. I think the more attention you pay to your sand the less trouble you are going to have in that particular. Also I think this, that what our friend has stated about the presence of slag in iron will cause this condition. I think if you go into the sand proposition, get the heaps right, the moisture right, you will go along a big distance to eliminate this trouble.

Porter Spencer: You stated that the fluidity of the metal didn't affect it appreciably.

E. Touceda: You speak of fluidity in general. We all know cold metal will produce blow holes and be more dirty cold than if it is hot.

H. A. Schwartz: I make a motion that the question of the method for the determination of the yield point in malleable iron be referred to the Committee on Malleable Iron Specification, in co-operation with the proper committee of the American Society for Testing Materials.

C. H. Burgston seconded the motion, which was unanimously carried.

Chairman L. C. Wilson: Of course, all motions that we pass are subject to the approval of the Board of Directors of the American Foundrymen's Association.

Resistance of Malleable Iron to Repeated Impact Stresses and Comparison of Strength of Machined and Unmachined Malleable Castings

By Enrique Touceda, Albany, N. Y.

Part I

Four malleable iron* and four cast steel American Railway Association combined back-stop and bolster center fillers, identical in design, were secured and subsequently tested by subjecting them to vertical static and drop tests, a record and description of which tests follows:

Two castings of each material were used in the first test conducted at The Fritz Engineering Laboratories of Lehigh University and two of each in a second test made at the Armour Institute of Technology, Chicago. The average weight of the four malleable iron and four cast steel castings were 142½ and 145 pounds, respectively. The compositions are given in Table 1.

Table 1

COMPOSITION

	Carbon Per cent	Manganese Per cent	Silicon Per cent	Phosphorus Per cent	Sulphur Per cent
Cast steel	0.24	0.49	0.25	0.027	0.040
Malleable iron	2.23	0.32	0.90		0.035

Tensile Tests

The test coupons were removed from each of the steel backstops, and from these standard tensile test specimens were machined and tested; while standard malleable iron test bars cast from metal from the same ladle from which the malleable castings

*The malleable iron back-stops and center fillers were made by The Symington Co. of Rochester, N. Y.

The tests at Lehigh University were witnessed by R. H. Graff, New York Central R. R.; Prof. M. O. Fuller, Lehigh University; Prof. H. G. Payrow, Lehigh University, and E. Touceda, Consulting Engineer, A. M. C. Association.

The tests at Armour Institute were witnessed by Prof. P. C. Huntley, Armour Institute; Messrs. Hoffman and Insink of the Symington Co.; J. B. Deisher, Assistant to the Consulting Engineer of the A. M. C. Association, and E. Touceda, Consulting Engineer of the A. M. C. Association.

were poured also were subjected to tensile test. The tensile test results are given in Table 2.

Table 2

AVERAGE TENSILE PROPERTIES OF THE TWO MATERIALS

	Yield Point Pounds per square inch	Tensile Strength Pounds per square inch	Per cent Elongation in 2 inches
Cast steel	42,000	53,740	21.8
Malleable iron	35,500	53,840	17.6

Also, flat specimens, ⅜ of an inch by ⅝ of an inch gauge were cut from the same location from companion back-stops in each case. The tensile test results of these specimens are given in Table 3.

Table 3

AVERAGE TENSILE PROPERTIES OF THE ⅜" x ⅝" FLATS

	Yield Point Pounds per square inch	Tensile Strength Pounds per square inch	Per cent Elongation in 2 inches
Cast steel	37,910	58,890	13.0
Malleable iron	34,910	52,380	18.0

Car Conditions Duplicated

The castings were assembled in a manner that duplicated car conditions as closely as possible by riveting back-stops to standard A. R. A. sill sections and riveting suitable cover plates to the sills at top and bottom of the back-stop, while a steel loading block of the same dimensions as a yoke was used during the test to insure a distribution of the load over the same area as occurs in service. Deflection readings were taken with special trains registering in punch marks on the casting and the base of the testing machine and are believed to be correct to within 0.01 of an inch. The deflection readings used in plotting the curves shown in Figs. 1 and 2 are average figures obtained from six measurements.

Loosening of rivets was carefully observed throughout the tests.

Static Tests

Static tests were made using the 800,000 pound tensile testing machine of The Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa. In these tests, the castings were given a settling load of 100,000 pounds, this being released to 20,000 pounds, which was taken as the datum load.

Drop Tests

Drop tests were made under the 9,000 pounds drop hammer at the Armour Institute of Technology, Chicago.

For this test castings were subjected to a settling load of five (5) blows from a height of 8 inches before any measurements were taken. Readings of deflection were taken from these measurements as datum. Subsequently the tup was raised by 4-inch increments until failure occurred.

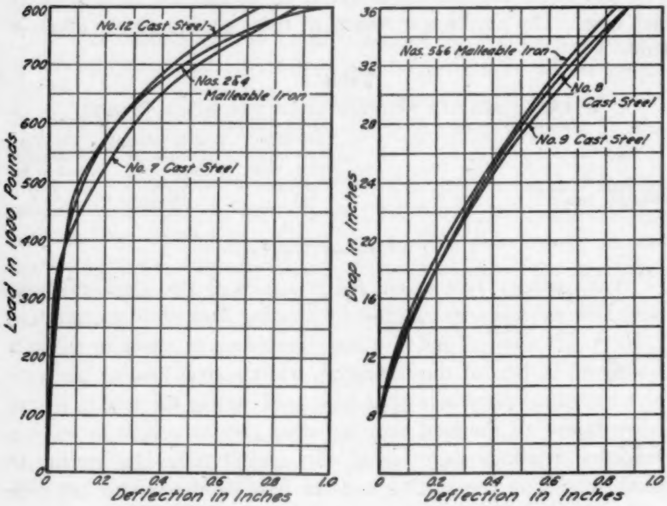

FIG. 1 FIG. 2

FIG. 1—STATIC TESTS OF CAST STEEL AND MALLEABLE IRON
FIG. 2—DROP TESTS OF CAST STEEL AND MALLEABLE IRON

Comparison of Properties as Shown by Test Results

A comparison of physical properties as determined from specimens cut from the castings, with properties determined from the malleable iron test bars and the bars from the steel test coupons, show the physical properties of the malleable iron to be more consistent in these castings than obtains in the case of the other metal. In other words, the tensile properties of the malleable iron castings

as determined from test specimens cut from the castings themselves are in closer accord with results obtained from the regular tensile test specimens than is the case with cast steel. This fact is brought out rather forcibly in the following.

In the case of the malleable castings, the yield point obtained from test specimens cut from castings showed only a 1.6 per cent deviation from the figure obtained from the regular tensile bars cast from the same ladle, while in the case of the cast steel, the yield point figure obtained from test specimens cut from castings showed a 10.8 per cent deviation from the figure obtained from the test coupons. Figures for ultimate tensile strength showed a deviation of 2.7 per cent in the case of malleable iron, but a deviation of 9.6 per cent in the case of the cast steel. Figures for elongation, per cent in 2 inches, showed a deviation of 2.3 per cent in the case of malleable iron, but a deviation of 40.4 per cent in the case of cast steel.

In general, it can be stated that the physical properties of malleable castings as determined by test of the castings themselves can be depended upon to show from 90 per cent to 95 per cent of the figures as obtained from regular tensile specimens.

Deflection Curves

A comparison of the deflection curves for the static tests shows that the deflection is about the same for both materials. Up to within 600,000 pounds the malleable iron back-stops stood about the same deflection as one of the cast steel, and slightly less than the other cast steel back-stop. In the drop tests both of the malleable iron back-stops showed slightly less deformation than those of cast steel. It is interesting and significant to note that in the malleable iron back-stop tests, the deflections throughout the range in the case of both the static and drop tests were so similar that two separate curves could not be plotted. This indicates that in the case of malleable iron more consistent duplication of physical structure can be depended upon. Also that greater exactness in duplication of sections can be depended upon for castings of malleable iron than for those made of cast steel.

Loosening of Rivets

The tests indicate a much greater tendency for the rivets to develop looseness in the case of the cast steel back-stops than

was the case in those of malleable iron. In general, it has been our experience that when rivets loosen in cast steel due to alteration in physical condition of the metal adjacent to the hole, they very seldom tighten up again, because as the stress progresses the resulting failure is more rapid than the relative movement of the two pieces riveted together. On the other hand, with malleable iron, the properties of the metal appear to be such that it accommodates itself to changes in the movement of the two riveted parts, which tighten up again.

Drop and Impact Tests

Referring again to the drop test on malleable and cast steel back-stops described in the foregoing, it can be seen that the deformation of the cast steel back-stops for a given impact load is greater than those cast from malleable iron throughout the range of the test. For instance, comparing the deformation, for the 24-inch blow of the tup, on castings of the two materials we find that the deformation of the malleable iron back-stops is 96 per cent of that of the cast steel back-stop in one case and 92 per cent in the other.

Also, the ability of malleable iron to withstand shock or repeated impact stresses recently has been demonstrated by tests made at the Armour Institute of Technology on four railroad car draft gears of the same design, two of which had malleable housings and two housings of cast steel. All four of these gears were given similar sturdiness tests under the 9,000 pounds drop hammer, the test being conducted in such a way that the housings were subjected a number of times to the direct action of the impact load. Examination of the housings at the end of the test indicated that in both cases the steel housings had shortened 1/16-inch in 13½ inches, while the two malleable iron housings were free from deformation.

Part 2

The standard malleable iron test bar is 7½ inches long; has a gauge diameter and length of ⅝-inch and 2½ inches respectively, with grip ends 2½ inches long and ¾-inch diameter. It is routine practice at the plants of the American Malleable Castings Association to cast a certain number of such bars from each heat, and after they have been malleablized to test them in the rough.

Owing to the fact that the gauge length is rarely, if ever, truly round and that due to kiln-warp the bars are seldom straight, it was the thought of many that were the test bars machined or ground in order that when tested the stress would be more truly axial, that the average tensile properties of such bars would be found to be considerably higher than those made on duplicate bars in the rough, that is, the tensile results on the former would more closely indicate the real facts regarding the tensile properties of the metal. In order to test this matter out, various lots of bars were cast, one lot consisting of 21 sets, each set being cast from a different heat, and from the same ladle of metal in each case. Two of the test bars were machined and one left in the rough. The second lot comprised 23 sets from as many heats, four test bars being poured from the same ladle of metal, 2 being ground and 2 being left as cast. The third lot was made up of 31 sets from different heats, 3 bars being cast from the same ladle, 2 being ground and one left in the rough.

Tensile Properties of Rough, Ground and Machined Bars

In Table 4 is recorded an average of each tensile property in the case of the machined, ground and rough bars, and the difference in pounds or per cent as the case required between the machined and duplicate rough bars, or the ground and duplicate rough bars. While in all three lots the average ultimate strength

Table 4

A COMPARISON OF THE AVERAGE TENSILE PROPERTIES OF THREE MISCELLANEOUS SETS OF TEST BARS*

	Lot 1 21 Sets	Lot 2 23 Sets	Lot 3 31 Sets
Average yield point of X bars (pounds)	35,960	38,255	37,843
Average yield point of Y bars (pounds)	36,808	36,939	36,581
Difference in favor of X bars (pounds)	0	1,319	1,262
Difference in favor of Y bars (pounds)	848	0	0
Average ultimate strength of X bars (pounds)	56,101	57,441	57,476
Average ultimate strength of Y bars (pounds)	55,573	55,991	55,660
Difference in favor of X bars (pounds)	528	1,450	1,816
Difference in favor of Y bars (pounds)	0	0	0
Average elongation of X bars (per cent)	23.54	23.15	23.38
Average elongation of Y bars (per cent)	22.55	22.18	21.49
Difference in favor of X bars (per cent)	1.00	0.97	1.89
Difference in favor of Y bars (per cent)	0	0	0
Average reduction of area of X bars (per cent)	22.81	22.34	22.34
Average reduction of area of Y bars (per cent)	21.11	23.14	23.02
Difference in favor of X bars (per cent)	1.70	0	0
Difference in favor of Y bars (per cent)	0	0.80	0.68

*Lot 1—Comparative average results between 21 sets consisting of two machined and one rough bar. Lot 2—Comparative average results between 23 sets consisting of two ground and two rough bars. Lot 3—Comparative average results between 31 sets consisting of two ground and one rough bar.

In all cases the letter "Y" indicates the rough bars.

of the machined bars is higher than the average of the duplicate rough bars, and in two cases out of three, in both of which the gauge length was ground, the yield point is higher in the ground than in the rough bars, the increase in these two properties would hardly warrant such expense as would be incurred if the bars were machined or ground, unless such increase was accompanied by a substantial betterment in both elongation and reduction of area, but particularly in the former. As the increase in average elongation is found to be quite inconsequential and the average reduction of area in two cases out of three is found to be in favor of the rough bar it is obvious that little, if any, advantage would accrue from the machining or grinding of the test bars.

Table 5 will throw further light on the situation if the results are compared with those in Table 4 as the latter deals with averages, while in the former is shown comparative figures for each

Table 5

No. of sets in which:	Lot 1* 21 Sets	Lot 2* 23 Sets	Lot 3* 31 Sets
The X bars were higher in yield point	5	21	29
The Y bars were higher in yield point	16	2	2
The X bars were higher in ultimate strength	14	23	31
The Y bars were higher in ultimate strength	7	0	0
The X bars were higher in elongation	11	17	17
The Y bars were higher in elongation	10	6	14
The X bars were higher in reduction of area	13	9	15
The Y bars were higher in reduction of area	8	14	16

*In Lot 1 "X" stands for machined bars. In Lots 2 and 3 "X" stands for ground bars.

property in the case of each lot. From these data it can be seen whether, on the basis of sets, the advantage lies with the machined or ground bar as compared with duplicate bars tested in the rough. It must be conceded that the results are quite unexpected.

Eccentric Stresses

The author believes that the answer to the question as to why the difference in favor of the machined and ground bars is not greater has to do with the ability of malleable iron, due to its combined ductility and plasticity to accommodate itself without injury to the action of eccentric stresses. This peculiarity has been noticed in service on many occasions and it is further illustrated in the tests on the back-stops in the case of the loosening of the rivets in those made of malleable iron as compared with those of cast

steel. In order to test this matter out in an exaggerated manner six test bars were taken in which the gauge length was ground, the grip ends left in the rough; their axis being extremely out of line with each other and with the axis of the gauge length.

Each was tested against a duplicate rough bar whose gauge length was ground and grip ends machined in order that the bar would be truly symmetrical and also against a duplicate rough bar. In the first instance the yield point was in favor of the unsymmetrical bar to the extent of 329 pounds; the ultimate strength to the extent of 1,124 pounds; the elongation by .24 per cent, while the difference in reduction of area was in favor of the machined bar by 1.83 per cent actual.

In comparison with the rough bar all of the properties are in favor of the unsymmetrical bar with the exception of the reduction of area, as obtained in the other case. The difference in yield point is 2,131 pounds; in ultimate strength 2,770 pounds; in elongation 0.34 per cent actual, while the difference in reduction of area in favor of the rough bar is 2.07 per cent actual.

To the author the results are surprising and he regrets that time is lacking in order to present to you a further series of tests that would serve to show definitely whether what is shown by a test on six bars only is out of line with what future tests will show. Malleable iron is a very unique material and when made as in present practice its ability to stand abuse is remarkable.

The tests contained in these tables clearly indicate also that the old thought, that when the skin of a malleable iron casting is removed it has lost its strength in large part, is incorrect. While this fact has been heretofore set forth by numerous writers, including the author, it has been thought worthwhile to again call attention to this matter. From the very carefully calipered diameters of the rough and duplicate machined bars and the ground and duplicate rough bars it was found that the diameter of the machined bars averaged .069 inches less than the average of the duplicate rough bars, and the average diameter of the ground bars averaged .060 inches less than that of the average of the duplicate rough bars.

Discussion

E. M. Handley: What is the reason of running phosphorus down as low as 0.03 per cent?

E. Touceda: That is the way back stops were made. Perhaps an effort was made to duplicate steel analysis as close as they could. It might have been a clerical error and the figure should be 0.13 per cent instead of 0.03 per cent.

E. M. Handley: Would it make better material?

E. Touceda: Yes. You know in wrought iron, the phosphorus is as high as three-tenths of one per cent. Phosphorus does not seem to injure the material to such an extent when the entire matrix is ferritic and free from pearlite.

F. M. Robbins: I would like to ask Mr. Touceda if he has any theories as to the reason for the close or slight variation in the yield point as given in the stops as compared to the variation in the yield point as given in the test bar?

E. Touceda: You will notice that in the pieces cut from each back stop the mechanical properties of the one cut from the malleable iron back stop was in one case higher than the corresponding test bar. In the case of the steel back stop, the piece that was cut from the casting was very much inferior to the test coupon. I would not want to say that this would always happen. It is very seldom you get a piece cut from casting that will exceed the test bar performance, and it is not expected that such could be the case, but, anyhow, the results that are stated here are actual facts.

E. M. Richardson: In putting those together, were they rough holes, or reamed?

D. M. Scott: They were reamed very carefully.

W. R. Bean: In connection with the question asked regarding phosphorous content, a few years ago we ran a series of tests, phosphorus from .01 to .135, about. In that test we included impact as well as tensile tests. The .01 phosphorous material was actually showed up less favorable than the phosphorus around .10 and higher, and also lower in the tensile strength and elongation, as I recall it. I am speaking now from memory. Those figures are in a paper which was presented at the February meeting of the A. I. M. E. in 1923. We were surprised to find there was no advantage in ordinary malleable iron with the lower phosphorus.

E. Touceda: Do you not think that was due to decreased fluidity?

W. R. Bean: We got it fluid.

A Study of Malleable Cast Iron[1]

Dr. O. Quadrat,[2] and J. Koritta,[3] Prague, Czechoslovakia

The object of the investigation described in this paper was to examine the influence of the temper carbon on the physical properties of the gray heart of malleable castings. The investigations were made on castings produced in the foundry of the engineering works of Ceskomoravska-Kolben Ltd., at Prague-Vysocany.

Analysis of Iron Used

The original white cast iron to be malleableized contained from 2.5 to 3 per cent of carbon, on an average 0.8 per cent of silicon, 0.08 to 0.14 per cent of manganese, 0.075 to 0.095 per cent of phosphorus and 0.05 to 0.07 per cent of sulphur.

Treatment of Iron

The castings were charged into cast steel vessels filled with Swedish iron ore and were heated in a gas furnace for a period of sixty hours at a temperature of from 920 to 1000 degrees Cent. (1624 to 1768 degrees Fahr.), after the furnace had been previously heated up for a time of sixty hours. The cooling period was sixty to seventy-two hours.

The fracture of the resulting material showed on the surface a layer from one to three millimeters (.04 to .12 of an inch) deep without any carbon. This layer passed without any visible transition abruptly into the gray iron of the casting. By its appearance and composition it corresponded with American "black heart" malleable iron.

In the first part of our investigation we examined the relation between the contents of temper carbon and the physical properties of the gray heart of malleable castings.

The necessary test pieces were cut from the gray heart of plates dimensioned 200 by 80 by 20 millimeters (7.88 by 3.15 by .788 inches.) The plates used for this purpose were molded and cast with every possible precaution in order to obtain the castings as dense as possible.

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[1] Presented on behalf of the Czechoslovakian Foundrymen's Association.
[2] Professor, Technical University of Prague.
[3] Chemical Engineer.

White Iron Analysis

Before malleableizing the white cast iron contained from 2.58 to 2.95 per cent of carbon, an average of 0.8 per cent of silicon, 0.08 to 0.14 per cent of manganese, 0.075 to 0.095 per cent of phosphorus and 0.05 to 0.07 per cent of sulphur. The samples used were selected from fifteen different heats, the contents of carbon ranging in each heat from 2.58 to 2.95 per cent.

The Annealed Iron Analysis

The gray heart of the malleable castings (after removal of the carbonless layer by a planer) showed from 2.46 to 2.90 per cent of temper carbon. Thus the initial total content of carbon lost through the process of malleableizing from 1.3 to 5.4 per cent of its value. From 95 to 99 per cent of the still remaining carbon was found to be in the form of temper carbon and the rest in the form of pearlitic cementite. Of the other elements of the malleable castings sulphur showed an increment of 1 to 7 per cent compared with the initial contents, which is apparently to be attributed to the contents of sulphur of the iron ore used in the process, which lost from 40 to 60 per cent of the original value of 0.2 to 0.4 per cent. On the contrary, when sand was used instead of iron ore the castings showed a certain loss of sulphur.

Results of Physical Test

The material was investigated as to its tensile strength and to its resistance to shock and compression (by the Brinell press). The corresponding elongation and reduction of area were measured.

As long as the carbon content was within the limits of 2.9 to 2.46 per cent the tensile strength raised quite uniformly from 25.8 to 29.9 kilograms (56.76 to 67.78 pounds) per square millimeter (0.0394 inches). This mutual relation between the increase of tensile strength and the decrease of carbon has been illustrated by a curve.

A similar relation has been found to exist between the increase of the resistance to compression (measured by the Brinell press) and the increase of the amount of temper carbon.

The measurements of resistance to shock gave the results of 1.43 to 1.77 kilograms (3.15 to 3.85 pounds) per square millimeter

(0.0394 inches) for the corresponding amounts of temper carbon of 2.89 to 2.46 per cent. But the results obtained for the intermedial values of carbon did not display a sufficient degree of uniformity. Therefore it was impossible to express the relation between the contents of temper carbon and the resistance to shock by a curve.

Practically the same can be said about the values for elongation and contraction of area, which were found to be 4.85 and 11.4 per cent for a temper carbon content of 2.89 per cent and 4.95 and 17.05 per cent for a temper carbon content of 2.46 per cent.

Effects of High and Low Temperatures Upon Physical Properties of Gray Heart of Malleable Castings

The following part of our investigation dealt with the effect of low and high temperature upon the physical properties of the gray heart of the malleable castings.

Resistance to Shock

At a temperature of —10 to —12 degrees Cent. (18 to 10 degrees Fahr.) the resistance to shock fell to 88 to 82 per cent as compared with the original value.

At 100 degrees Cent. (212 degrees Fahr.) the resulting tensile strength amounted to 83 to 97 per cent of the original value measured at the ordinary temperature, the elongation 74 per cent and the contraction of area 79 to 92 per cent of the respective original values. When the test piece was heated to 200 degrees Cent. (392 degrees Fahr.) the tensile strength was 91 to 92 per cent, the elongation 73 per cent and the contraction of area 92 to 97 per cent of the corresponding original value. The resulting resistance to shock showed at temperatures of 100, 200 and 300 degrees Cent. (212, 392 and 572 degrees Fahr.) 93 per cent, 88 per cent and 92 per cent of the original value.

Further investigation has been conducted in order to determine the changes in resistance to shock of the gray heart of malleable castings heated to a temperature of 600, 700 and 800 degrees Cent. (1112, 1292 and 1472 degrees Fahr.):

(a) When cooled slowly down in an electric tube furnace for a period of four hours.

(b) When cooled slowly in air.

(c) When quenched in water.

Heating to 600 degrees Cent. (1112 degrees Fahr.) and cooling down as indicated in (a) and (c) had no appreciable influence upon the resistance to shock which has been lowered to 98 per cent of the original value. When quenched in water the test piece retained 94 to 96 per cent of its initial resistance to shock.

When heated to 700 degrees Cent. (1292 degrees Fahr.) and cooled down as indicated by (a) and (c) the resistance amounted to 97 to 94 per cent of the original value, when quenched in water the resistance amounted to 88. per cent.

Cooling down from a temperature of 800 degrees Cent. (1472 degrees Fahr.) according to (a) and (c) resulted in a resistance of 85 to 84 per cent of the original value, quenching in water decreased the resistance to 47 per cent of the initial value.

Similar trials with test pieces heated to a temperature of 950 degrees Cent. (1742 degrees Fahr.) and cooled slowly down in an electric tube furnace showed 22 per cent of the original resistance to shock, 13 per cent when cooled in air and 10 per cent when quenched in water.

Tensile Strength

The tensile strength of test pieces heated for an hour at a temperature of 950 degrees Cent. (1742 degrees Fahr.) and cooled slowly down in an electric tube furnace was 53.6 kilograms (117.9 pounds) per square millimeter (0.039 inches) against 36.8 kilograms (80.96 pounds) when cooled slowly in air and 3 to 4 kilograms (6.6 to 8.8 pounds) when quenched in water. The initial tensile strength of the same material amounted to 28 kilograms (61.6 pounds) per square millimeter (0.0394 inches), whereas when an original ductility had been obtained of 9 per cent the test piece treated in the way described above showed practically no ductility at all. The chemical analysis of the test piece heated for an hour at a temperature of 950 degrees Cent. (1742 degrees Fahr.) and then quenched in water showed not more than 1.4 to 1.6 per cent of temper carbon or 50 to 58 per cent of the original contents of 2.80 to 2.84 per cent. The 42 to 50 per cent, representing the rest of the carbon, passed by the effect of the heat into cementite respectively of "gama" mixed crystals.

Even when slowly cooled down for a time of four hours the dissolved part of the carbon did not return into the original form of temper carbon. Beside the chemical analysis the metallographic method has been employed in order to investigate the rate of decrease of temper carbon and of its dissolution.

Tensile Strength of the Ferritic Material Containing Grains of Temper Carbon

A further object of our investigation was to determine the tensile strength of the ferritic material containing the grains of temper carbon in malleable castings.

For that purpose we assumed the cohesion between the ferritic mass and temper carbon to be practically 0. With the specific gravity of the ferritic mass being 7.75 and the specific gravity of temper carbon being 2.2 the volume of the temper carbon was found as being equal to 8.5 to 10 per cent of the total volume. Consequently the surface of the gray heart contained 91.5 to 90 per cent of ferritic texture and 8.5 to 10 per cent of temper carbon.

On the premise that there is no cohesion between the ferritic mass and the temper carbon, then as a result of multiplying the original value of the tensile strength by the ratio of the total surface to the reduced surface of the ferritic mass we get the tensile strength of the ferritic as being equal to 30 to 32.8 kilograms (66 to 72.16 pounds) per square millimeter (0.0394 inches).

Defects in Steel Castings in the Foundry

By R. S. Munson,* Chester, Pa.

As shown by the title this paper will discuss only the defects in steel castings which are evident in the foundry during manufacture, and will make no reference to defects developing in the machine shop, which are covered in another paper. The defects considered are not only those serious enough to cause scrapping of the casting, but also minor defects which can be satisfactorily repaired, though at an added cost. This problem of defects is an ever-present one with each steel foundryman, and together with cost and deliveries, both of which it vitally affects, are the daily bane of his existence.

Theoretically, if one perfect casting can be made from a pattern it should be possible to make any number of perfect castings from the same pattern. How difficult of achievement this is is borne out by the daily experience of any steel foundry. Castings made from the one pattern by the same molder at the same time, and poured from the same heat, will show varying individual defects often hard for the foundryman to explain.

A few years ago an article by Michael R. Burns appeared in *The Foundry*, entitled "Fifty Causes of Defects in the Foundry." In this paper the author enumerated in detail fifty causes of defects. He further stated that, in view of the almost innumerable possibilities of defects in a casting, the wonder is not that there are so many defective castings, but rather that the percentage of good castings is as high as it is.

It is not the purpose of this paper to enumerate all the defects which do or may occur to steel castings in the foundry, nor to attempt to offer remedies for each individual defect, for these remedies may differ as much, according to the individual judgment of different foundrymen, as the defects themselves.

For example, a shrinkage crack in a casting may be remedied by the changing size or location of heads, using brackets or

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cracking strips or by the use of inside or outside chills, any one of which may solve the trouble. The method used depends entirely on the judgment of the foundry foreman.

Speaking generally, however, the causes of defects in steel castings in the foundry can be placed under three main heads:

1. Design and pattern equipment.
2. Molding and core shop methods.
3. Melting and pouring conditions.

These causes are mentioned in their sequence in the cycle of operations, and will be considered in that order.

Defective Design of Patterns

In the matter of design, especially in the jobbing foundry, the steel foundryman is often the unwilling and unhappy victim, since most of the castings he makes are designed by his customers, and in many cases the engineer in his effort to limit weight or decrease assembly costs designs a casting not consistent with good steel foundry practice. Most steel foundrymen could cite instances from their own experience where, after suffering heavy losses in the foundry from castings of this character, they have made changes in the original design, in order to conform to good steel foundry practice, by which they have been able to produce satisfactory castings without great loss from defects. This of course does not apply to experimental work, where the customer is trying to develop a design with the assistance of the foundry, but rather to the regular run of work which the steel foundry concerned has taken at a fixed price and on which they expect to make a profit. Nor does it apply to the foundry making specialties of their own design where the engineer has taken steel foundry problems into consideration.

In order to reduce the defects from this cause the steel foundry should insist that its customer's engineers consult with them as to castings of new or intricate design. By doing this it is possible to work out the problems beforehand satisfactorily and save losses to the foundry and vexatious delays to the customers.

A somewhat similar condition prevails with pattern equipment, as in most cases this, too, is furnished by the customer without consultation with the foundry concerned as to the most suitable method of construction. A solid pattern may be furnished when a split pattern would be preferable, or the split pattern furnished may be parted wrongly. Core boxes may be furnished when it would be better for the pattern to make its own cores, or the reverse may be the case. Blueprints may not be furnished so patterns can be checked for shrinkage, nor are patterns always marked to show finish.

The physical condition of the patterns may be such that they will not last for the order, and so cause defective castings. This question has been treated very ably in detail by W. J. Gilmore in a paper entitled "Pattern Expense from the Jobbing Foundry Point of View," presented before the Steel Founders' Society of America in July of this year. In this paper the author showed clearly and definitely the losses to the steel foundry from poor pattern equipment furnished by customers and accepted by the foundry.

If all customers could be convinced of the advantages to themselves, as well as to the steel foundries, of constructing their patterns in accordance with the standard method sponsored by the American Foundrymen's Association, the Steel Founders' Society of America and other foundry organizations, many of the difficulties mentioned would be overcome. To accomplish this it is necessary for the foundries to cooperate whole-heartedly in educating customers along these lines. Too often in anxiety to secure an order the question of design and proper pattern equipment will be overlooked, and the foundry securing this order find itself facing the problem of producing castings of impracticable design from poor pattern equipment without sustaining severe losses from defects due to either or both of these causes.

Heading and Gating

When a pattern of proper design and construction is ready for production the first problem of the foundry and core shop foremen in securing a satisfactory casting is that of proper

heading and gating. This calls for their best judgment, as from this point on each casting becomes an individual problem and any mistakes in heading and gating will cause similar defects in each casting, in addition to whatever individual defects they may fall heir to.

If heads are too small shrinkage will develop, if too large metal is wasted and the large head may crack the casting. If not properly gated, scabby, misrun or cracked castings may result. As this is so much a matter of individual judgment on the part of the foreman, and, as his judgment is based largely on his previous experiences with castings of similar design, it would seem advisable to help him by keeping a careful record of previous methods, both satisfactory and unsatisfactory, rather than forcing him to rely entirely on his own memory. With the benefit of this previous experience definitely placed before him he is in much better position to avoid defects in the castings arising from mistakes in judgment.

Flask Equipment

It seems unnecessary to mention the need for good flask equipment, but due to the hard usage to which flasks are subjected in a steel foundry, particularly those flasks used for dry sand, it is not unusual to find flasks in such condition that they are the cause of various defects in the castings. Warped flasks with bad joints and poor pinholes may be seen in daily use, resulting in shifted, crushed or heavily finned castings.

Molding and Core Sand

With proper pattern equipment to place in suitable flasks, the next problem for the foremen is that of a proper molding and core sand. Each steel foundry, no doubt, uses the most suitable sands and clays for their class of work which are obtainable in their particular locality. It is essential, however, that this sand be properly conditioned both for use in molds and cores, with particular reference to the character of the castings to be made. It can only be decided by results obtained which is the best sand or combination of sands to be used. Once this is determined the sand should be kept to these standards, not

only from day to day, but from hour to hour in order to insure the uniformity desired. This can best be done by laboratory equipment, for the old method of testing by the "feel" will cause too wide variations.

The moisture content, permeability and strength of the sand should be carefully determined. This will of course vary, depending on whether the sand is used for green sand or dry sand molds, also on the size of the casting to be made. A green sand too wet or too close will cause blowy or scabby castings, one too dry dirty castings. A dry sand too wet will cause cracked molds in drying, with the possibility of dirty castings. A sand too strong will make too hard a mold, which will crack the casting; one too weak will result in crushed or dirty castings.

In dry sand work burned molds or molds not thoroughly dried will also cause some of the defects mentioned. Considering the great number of defects in steel castings, which are directly traceable to poor sand conditions, it is evident that a great deal can be done in the way of improvement of conditions along these lines.

While the sand committees of the American Foundrymen's Association have done very valuable work in sand investigation, it would be possible for individual foundries in adjoining localities using the same source of supply to extend this work with great practical benefit to themselves. By cooperating more closely in determining the best sands available, and also the best methods of conditioning them, they should be able to materially reduce defects from sand conditions. It would seem that there are great possibilities for further research along these lines.

Proper Methods in Molding

With the use of the best equipment and raw materials the foundry foreman and core shop foreman still face the task of properly making molds and cores so that when closed and poured the resulting castings will be satisfactory. This becomes largely a problem of workmanship, such as proper ramming, nailing and venting of molds and cores. As each casting is individual so is each workman, and the individual casting tends to reflect the efforts which the individual workman puts into it.

Need for Apprentice Training

In spite of the prevalence of machine production, there is still a great need for skilled workmen. In every shop there are always certain outstanding workmen whose product is superior to that of their fellow workmen, as shown by the small number of defective castings coming from their floor. And perhaps the defective castings in a steel foundry reflect more accurately than is thought the character of the personnel of that foundry. If this be true all efforts along the line of improving the character of the personnel would be amply repaid. A good example of what can be accomplished along these lines is illustrated by the results obtained by the Milwaukee group of steel foundries with their apprentice system.

There is no doubt that this group of foundries is benefiting and will still further benefit from their efforts in properly training young men for the foundry trades. This subject, which can only be touched upon in this paper, is a great problem in itself, and we are at present only concerned in its effect on eliminating defects in steel castings. Any improvement in personnel, however, brought about will be reflected in a smaller number of defective castings.

Technical Control

The actual making of steel in the foundry has probably received closer attention from technically trained men than has either the pattern shop or the foundry proper. Nearly every steel foundry has its own physical and chemical laboratory with a chemist or metallurgist in charge. Most of his time has been given to the metal end of the industry, which probably justifies the assumption that from a scientific standpoint it is ahead of the other operations. Yet in spite of this many defects in steel castings are directly traceable to the melting and pouring of the metal. Wild heats are not unheard of nor are all heats properly made otherwise. The pouring temperature of the metal may not be correct for the castings to be poured. If too hot, castings of certain designs may crack or the sand burn in badly. If too cold, misrun or dirty castings result.

Other defects may arise from improper pouring on the part of the ladlemen, such as strained molds from too rapid pouring, or misrun castings from too slow pouring. The melter and ladlemen should be informed as to the nature of the castings in the molds to be poured so that metal is tapped at the proper temperature and poured into the mold with due regard to its individual characteristics.

It is the proper combination of all the conditions affecting patterns, molds and metal that makes possible castings free from defects. Failure in any one of them will cause defects of varying degree. The number and extent of these defects often means the difference between profit and loss, and is the daily problem of every steel foundry.

Cooperation

The solution of this problem is an important task of foundry management, and like many other human problems can be more easily solved through cooperation. Cooperation in educating the customer to the necessity of castings of proper design, and pattern equipment of suitable construction. Cooperation by adjacent foundries in securing the best available raw materials and determining the best possible combination of these materials, and in endeavoring to improve the personnel of their plants by training apprentices. Cooperation in research work to better the quality of the product by improving present methods of manufacture or devising new ones. Only by striving for ultimate perfection of product will defects be eliminated and the status of the industry as a whole advanced.

Defects in Steel Castings Discovered After Shipment from the Foundry

By J. M. Sampson,* Schenectady, N. Y.

Defects in steel castings as found after shipment from the foundry, aside from surface defects which should be discovered by proper inspection prior to shipment, may vary somewhat in their relative importance as measured in costs to the foundry, depending upon the practices in varying foundries. These varying practices may be considered as follows: whether open hearth, electric, converter, basic or acid hearths. Whether green or dry sand. Varying percentage of riser or feeder metal for a given casting. Gating practice on a given casting. The extent to which internal chilling is carried on a given casting.

Naturally, the tabulation (later given), which indicates the relative importance or per cent of defects in castings in the machine shops, pertains only to the plant with which the writer is connected.

All of the steel castings we produce at Schenectady works of the General Electric Co., are machined within our own plants and approximately 80 per cent are machined at the Schenectady works.

All defects when they are found in the machine shops are covered by inspection reports, copies of which are sent to the foundry producing the casting. This report endeavors to indicate the nature of the defect, its location, the amount of work done before such discovery was made and usually a recommendation as to disposal—whether to condemn it or to salvage it. If the latter, a further recommendation is made as to what should or will be done, before the casting can be passed into production.

These inspection reports are sent to the foundry inspector foreman and to a man within the foundry organization, who is a skilled foundryman, and who does nothing else except follow up machine shop complaints and keeps in close touch with the methods being used in making all troublesome castings. This

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foundryman, or trouble man, confers with the foreman responsible for making the casting and proper precautions are outlined for producing the casting the next time it comes into the foundry. Two drawings (blue-prints) are marked up, showing the defect, its location, gating and risering, probable cause or causes of the defect, and also the method to be used the next time the casting is made. A record is kept of all such drawings that are on file, and all incoming orders are checked to see if any of them are for these past offenders. If so, one of these drawings is sent along with the job and it is up to the foreman to see that the proper method, as outlined, is used.

This procedure became necessary because we found that many jobs, that had given us trouble and then been conquered, were often made, on subsequent orders by some old and improper method, sometimes even when made by the same workman who had formerly used the correct method. I believe all the foundrymen present have had the same exasperating experiences.

It might be interesting to note the relation existing between castings discounted in the foundry, rejections in the machine shops and labor on defectives in the machine shops. With that view in mind, the tabulation below is presented: The percentages given are not by weight, but represent the percentage of the total transfer prices, or total amount credited to the foundry. The amounts credited to the foundry represent actual costs.

Year	Per Cent Total Loss	Per Cent Discount in Foundry	Per Cent Rejected in Mach. Shops	Per Cent Labor on Defectives
1923	9.38	4.49	3.88	1.01
1924	8.76	3.93	3.98	0.85
1925	7.69	3.40	3.67	0.61
1926 (first six months)	6.72	3.69	3.03	....

To obtain a little better picture of the tabulations given, we will show what they become in percentage of weight cast and per cent of value cast: (This is done by multiplying the percentages of each item, or cause, by the proper percentage in Table 1.) During this six month period, the discounts in the foundry and rejections in machine shops, totalled 5.53 per cent by weight, of the cast weight, or 6.72 per cent in value, of the cast value. It will usually be found, however, that the percentage in value is less than the percentage by weight.

During this same period, approximately 40 per cent by weight and 40 per cent in value of the total cast required additional work done on them, before they could be passed into production. This may seem exceedingly high until you realize that absolutely no welding was permitted in the foundry. Whenever, in the opinion of the inspector, a casting could be used by a small amount of welding, it was sent to the proper machine shop, where it was either salvaged or condemned. It should also be remembered that the least bit of additional work, whether chipping, welding, grinding, straightening, etc., has to be covered by an inspector's report.

This practice was the outcome of a desire on the part of the engineers, to be sole arbiters of what defects could be remedied by welding, patching, etc. I might say, in passing, that this condition came about because there were no inspectors in the foundries until less than two years ago. This restriction against welding is now being removed and power given to the inspectors in the foundry to permit and supervise welding of all minor defects. This will greatly reduce the percentage now being salvaged in the machine shops, and eliminate a great many delays.

Referring to Tables 2 and 3, these various causes may be arranged into four groups:

MC—due to molding or coremaking.
MT—due to metal.
CR—due to fault of cleaning room.
OD—due to departments outside of foundry.

Referring to Tables 4 and 5, these various causes may be grouped as in Table 6.

Referring to Table 7 we note that nearly 2.5 per cent of the value of the total cast is rejected in the machine shops, and nearly 39 per cent is salvaged, all due to the foundry. The per cent rejected probably is not exceptional considering the class of work produced, and the rigidity of inspection in the machine shops. However, there is approximately 10 per cent salvaged, due to cleaning room faults, all of which should have been prevented by better workmanship and supervision in the cleaning room.

Table 1

CASTINGS REJECTED IN MACHINE SHOPS

Period January to June, Inclusive

	Per Cent by Weight	Per Cent by Value
Shipped	97.32	96.31
Discounted in foundry	2.68	3.69
Rejected in machine shops	2.85	3.03
Salvaged in machine shops	39.80	40.20

Table 2

CASTINGS REJECTED IN MACHINE SHOPS

Period January to June, Inclusive

Group		Cause	By Weight in Per Cent of 2.85 Per Cent Rejected in Mach. Shops	By Value in Per Cent of 3.03 Per Cent Rejected in Mach. Shops
MC—	1.	Shrinkage holes	36.66	34.40
MT+	2.	Blow holes and porosity	10.10	14.34
MC—	3.	Dirt and slag	14.27	12.24
MC—	4.	Cracks uncovered (shrinkage mostly)	13.78	11.09
OD×	5.	Machined wrong	12.01	11.04
OD×	6.	Pattern shop faults	4.61	6.42
MC—	7.	Core set wrong	1.74	1.80
MT+	8.	Cold metal	1.22	1.80
CR O	9.	Grinding (cleaning room)	1.16	1.70
OD×	10.	Miscellaneous (mostly engineering faults)	1.26	1.31
MC—	11.	Shifted	0.89	0.88
CR O	12.	Burning off (cleaning room)	0.48	0.80
CR o	13.	Broken in handling	0.45	0.76
MC—	14.	Core wrong	0.74	0.75
MC—	15.	Crushed mold	0.63	0.67
			100.00	100.00

Table 3

CASTINGS SALVAGED IN MACHINE SHOPS

Period January to June, Inclusive

Group		Cause	By Weight in Per Cent of 39.80 Per Cent of Table 1	By Value in Per Cent of 40.20 Per Cent of Table 1
MC	1.	Shrinkage holes	17.88	23.29
CR	2.	Miscellaneous cleaning (mostly adhering sand)	22.19	18.29
MC	3.	Dirt and slag	19.43	16.32
MC	4.	Core set wrong	5.24	5.38
MC	5.	Core wrong	1.62	5.35
MT	6.	Blowholes and porosity	4.63	4.74
MT	7.	Cold metal	4.75	4.01
CR	8.	Burning off	3.61	4.00
MC	9.	Cracks uncovered (mostly shrinkage)	4.96	3.92
MC	10.	Shift	4.92	3.92
CR	11.	Grinding	3.65	3.31
MC	12.	Strained	2.58	2.82
OD	13.	Pattern shop	2.56	2.44
MC	14.	Pattern wrong (loose pieces misplaced)	0.83	1.21
OD	15.	Machined wrong	0.75	0.59
MC	16.	Crushed	0.40	0.41
			100.00	100.00

Table 4

MACHINE SHOP REJECTIONS

In Percentages of Weight Cast and Value of Cast

Group		Cause	Per Cent Weight of Cast	Per Cent Value of Cast
MC	1.	Shrinkage holes	1.045	1.042
MT	2.	Blow holes and porosity	0.288	0.434
MC	3.	Dirt and slag	0.407	0.371
MC	4.	Cracks uncovered	0.393	0.336
OD	5.	Machined wrong	0.342	0.334
OD	6.	Pattern shop faults	0.130	0.195
MC	7.	Core set wrong	0.050	0.055
MT	8.	Cold metal	0.035	0.054
CR	9.	Grinding (cleaning room)	0.033	0.052
OD	10.	Miscellaneous (mostly engineering faults)	0.036	0.040
MC	11.	Shifted	0.025	0.027
CR	12.	Burning off (cleaning room)	0.014	0.024
CR	13.	Broken in handling	0.013	0.023
MC	14.	Core wrong	0.021	0.023
MC	15.	Crushed mold	0.018	0.020
			2.850	3.030

Table 5

SALVAGED IN MACHINE SHOPS

In Percentages of Weight Cast and Value of Cast

Group		Cause	Per Cent Weight of Cast	Per Cent Value of Cast
MC	1.	Shrinkage holes	7.12	9.36
CR	2.	Miscellaneous cleaning (adhering sand)	8.83	7.35
MC	3.	Dirt and slag	7.73	6.56
MC	4.	Core set wrong	2.09	2.16
MC	5.	Core wrong	0.64	2.15
MT	6.	Blow holes and porosity	1.84	1.91
MT	7.	Cold metal	1.89	1.62
CR	8.	Burning off	1.44	1.61
MC	9.	Cracks uncovered	1.97	1.58
MC	10.	Shifts	1.96	1.57
CR	11.	Grinding	1.45	1.33
MC	12.	Strained	1.03	1.13
OD	13.	Pattern shop	1.02	0.98
MC	14.	Pattern wrong (loose pieces wrong)	0.33	0.49
OD	15.	Machined wrong	0.30	0.24
MC	16.	Crushed	0.16	0.16
			39.80	40.20

Table 6

	Rejected in Machine Shops		Salvaged in Machine Shops	
Group	By Weight in Per Cent of the 2.85 Per Cent	By Value in Per Cent of the 3.03 Per Cent	By Weight in Per Cent of the 39.80 Per Cent	By Value in Per Cent of the 40.20 Per Cent
MC	68.71	61.83	57.86	62.62
MT	11.32	16.14	9.38	8.75
CR	2.09	3.26	29.45	25.60
OD	17.88	18.77	3.31	3.03
	100.00	100.00	100.00	100.00

There is also about 25 per cent salvaged due to coreroom or molding defects, and analysis of the preceding tables shows that approximately 11 per cent is due to internal shrinkage and 14 per cent due to careless molding or coremaking. It is within this 25 per cent that the greatest loss occurs. While salvaging costs money, it is only a small part of the losses incurred. The extra machine work, re-annealing, disturbance of schedules and delivery to customer are by far greater in magnitude.

It is doubtful if foundrymen, generally, unless working in unusually close touch with the shops machining their castings, appreciate these losses contingent upon defects found in the machine shops.

Table 7

	Rejected in Mach. Shops		Salvaged in Mach. Shops	
Group	Per Cent of Weight of Cast	Per Cent of Value of Cast	Per Cent of Weight of Cast	Per Cent of Value of Cast
MC	1.959	1.874	23.03	25.16
MT	0.323	0.488	3.73	3.53
CR	0.060	0.099	11.72	10.29
OD	0.508	0.569	1.32	1.22
	2.850	3.030	39.80	40.20
OD—Foundry	0.508	0.569	1.32	1.22
	2.342	2.461	38.48	38.98

It is hoped that the tables shown herein, while only applying to one foundry, operating without welding equipment, may show how necessary it is to see the situation from the machine shop's point of view.

Causes of Internal Shrinkage and Cracks Studied

Since internal shrinkage and cracks due to such internal shrinkage causes a large part of the trouble and expense in machine shops, we have had for a considerable time, one man who does nothing but follow up this phase, particularly with small and medium sized castings. Whenever possible, a sample casting is made, gated and risered as deemed best, and then sawed through those sections likely to show shrinkage. If it is not defective the pattern is passed into production and a record made of the method used. If the dissection of the sample or samples shows defects

the method is changed until satisfactory results are obtained. A record is kept of all such original and changed methods. Some of these typical cases have been included in this paper. Possibly they may be of interest.

The casting shown in Fig. 1 is a good example of how the rushing in of a new pattern with an unreasonable shipment date specified will result in foundry trouble with consequent delays and inconvenience in the machine shop.

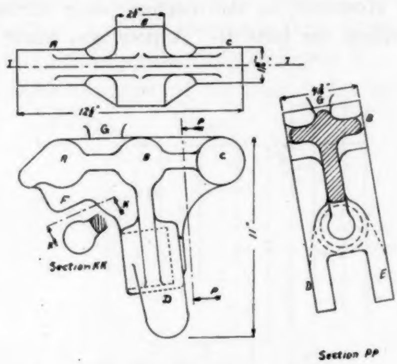

FIG. 1—WEIGHT OF CASTING 32 POUNDS

The pattern was taken out of malleable iron production, sent in to the steel foundry with a rush order of six castings attached. After studying the job, the foundry foreman had it molded as follows:

Gate at G—Joint along line JJ.
4 inch diameter risers 9 inches high at A, B and C.
4 inch by 3 inch by 9 inch high riser at D.
2 large horseshoe nails at F.
6 small horseshoe nails at E.

When castings were cleaned, shrink holes were found under each of the risers at A, B and C.

The relatively small diameter of the bosses A, B and C as compared to their depth, made it impractical to put larger risers

on the bosses, as it was thought that the 4 inch risers should feed the castings were it not for the small riser neck. To prevent the shrinkage from occurring under the risers at A, B and C the following chills were added, the heading remaining the same as that in the original method.

10 large horseshoe nails under risers at A and C.

2-80 penny spikes and 4 large horseshoe nails under the riser at B.

The castings made by this method when cleaned were apparently sound. However, in the machine shop shrink holes were exposed in drilling the boss B. A note was made of this fact,

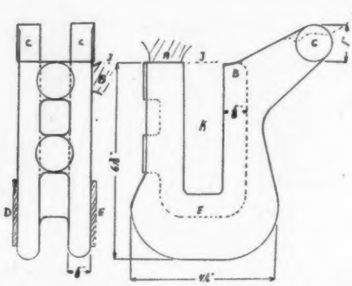

FIG. 2—WEIGHT OF CASTING SEVEN POUNDS

and so filed as to be brought to the attention of the foundry foreman, should the pattern come in again for another order. A sketch was made showing the method used in making the defective castings, and a note made to the effect that on the next order the boss B should be made of larger diameter so as to allow a larger riser.

It was suspected that this job would cause trouble, and had the foundry had time to make a sample and explore it, not only would money have been saved, but the machine shop would have had good castings sooner than they did by rushing the foundry.

Gating Causes Trouble

Fig. 2 shows a casting which caused trouble due to a combination of causes. The mold was originally made as follows:

Green sand—Joint along line JJJ.

3 inch diam. by 6 inch high head at A.

Gate at B.

External flat chills at D and E.

The castings were apparently all right until the bosses CC were milled and drilled. Large blow holes were found in these bosses. The reasons for this were obvious. The chills at D and E were serving no useful purpose in the bottom of the mold; in fact they prevented the riser at A from exerting its pressure down into the bottom of the mold and then up into the boss C. The feeding was cut off by the chills at D and E.

Having received notice of the blow holes occurring in the

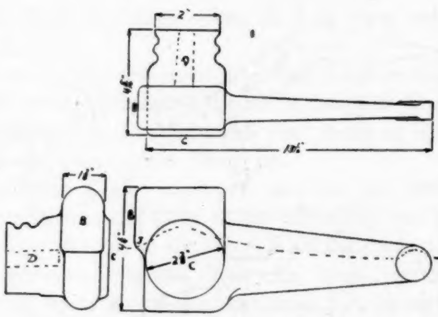

FIG. 3—WEIGHT OF CASTING 12 POUNDS

boss C, the foreman had the chills at D and E omitted (no one ever knew why they were put there in the first place, except the molder and he couldn't tell). The riser was also carried directly across the dry sand core K. The proximity of the riser at F to the bosses CC resulted in the bosses being perfectly sound. This method has been used ever since with no more trouble having been reported.

Fig. 3—Stubborn Shrinkage Trouble

Fig. 3 shows a job that presented stubborn shrinkage trouble. It was thought impractical to put a riser on top of the section

of the casting B, due to the fact that it would not be possible to make a good job of removing the riser and grinding the casting. The mold was made as follows:

Green sand—Joint along line JJJ.

4 inch side risers at B and C.

1—½ inch chill rod at D.

The metal was poured down the side riser at C.

Reports from the machine shop were to the effect that shrinkage was encountered in front of the side riser at B. To overcome this difficulty the mold was made in the same way as at first with the exception that the two side risers B and C were connected by a gate, outside of the mold cavity. This introduced hot metal into the side riser at B, eliminating the very short, but equally

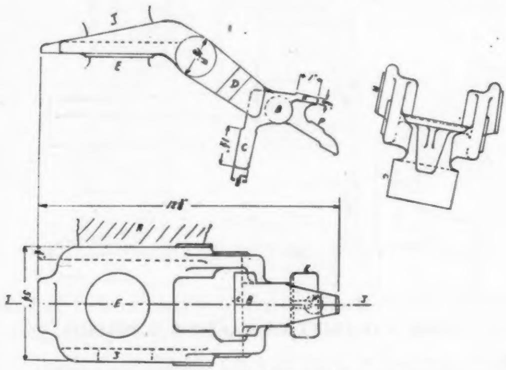

FIG. 4—WEIGHT OF CASTING 13 POUNDS

harmful travel of the metal down into the casting from C up into the side riser B. The slight difference in the temperature relation between the casting at point B and the neck of the side riser thus produced was sufficient to result in a sound casting.

Fig. 4—Shrink Holes and Blow Holes

The casting illustrated in Fig. 4 is one of the most troublesome ever had in the Schenectady foundry. These castings have been made here for nearly ten years, shrink holes and blow holes turning up in a large part of every order.

When the job was finally singled out and attacked with a view to overcoming the shrinks and blows, it was found that the original method of making the job was as follows:

Green sand drag—dry cope—Joint on JJ.

Riser over top of casting at A—Large gate at E.

Horseshoe nails in boss B and lugs or pads C, D, K, and P. These nails were put in both cope and drag, whistlers being taken up through the cope from the top of the pads C, D, K, P.

The castings looked all right when they left the foundry, but in the machine shop shrinks and blows were exposed in milling and drilling the pads C, D, K, P, and very spongy metal was found when the boss E was milled. Obviously, it was wrong to have the gate into the boss E. The method was then changed to be as follows:

Green drag—dry cope—Gate at J in drag only—Risers at A-C and K.

Chill nails under the risers at K and C and in boss B.

These castings showed a shrink in the pads K and C due to the fact that the metal in the small riser necks at K and C froze, preventing the risers from filling up.

The method finally employed, and the one which produced sound castings, was the same as the preceding one except that a gate or trough was cut in the top side of the cope, connecting the two small risers over K and C with the large riser over A. The metal flowing up freely in the large riser ran through these gates or troughs in the cope and dropped into the small risers over C and K, thus furnishing relatively hot metal to feed the pads C and K.

Fig. 5—Pattern Not Adaptable to Molding Method

The casting shown in Fig. 5 presents an example of a case in which the failure of the foundry man to have the pattern made to be most adaptable to the molding method contemplated resulted in faulty castings being shipped.

It will be noticed that the boss A in front of the gate has sharply tapered sides. The finish allowance put on the pattern was made to carry the same taper as the sides of the boss. In order to feed the casting at this point by means of the gate it was necessary for the gate to be cut out to almost the same diameter

as that of the boss, resulting in an inadequate mark being left as a guide for burning and grinding. A large number of castings were shipped out with too much stock ground off the face of the boss.

This could have been remedied and will be remedied in the future by having the finish on the face of the boss brought straight out, paralleling the axis of the boss. This will leave more room for the gate and, consequently, more room for the leaving of a plain mark to serve as a guide for the burners and grinders.

Fig. 6—Blow Holes Possibility in Small Casting

The experience had with the casting illustrated in Fig 6 goes

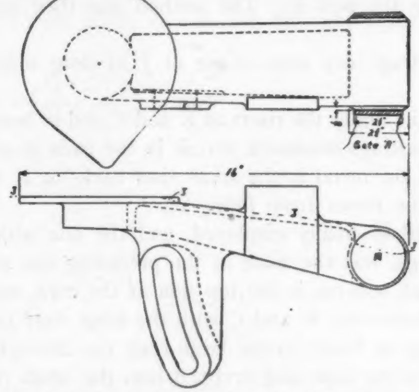

FIG. 5—WEIGHT OF CASTING 26 POUNDS

to show that blows are apt to be a more treacherous possibility than are shrinks, as regards small castings.

Many castings were made under the following method, and all were found solid in the machine shop.

Green sand.

4 inch Riser at A, 9 inches high—Joint on JJ.

3 inch by 5 inch Riser at B, 9 inches high.

1 Horseshoe nail at D—Gate at C.

A report was received from the machine shop saying that blow holes were being found in the small boss D, fourteen castings being found to have these blow holes.

There being no way for air, steam, or gas to escape from the pocket at D other than through a whistler; gas, air or steam had been pocketed and failed to escape through the whistler before the metal set. This was probably due to the molds having been damp, or the metal a little colder than usual. The chances are that a similar set of circumstances would not be encountered again for some time, and that no frequent trouble could be expected

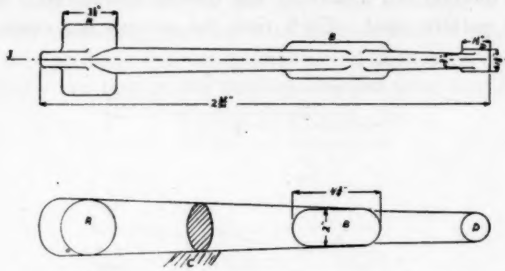

FIG. 6—WEIGHT OF CASTING 30 POUNDS

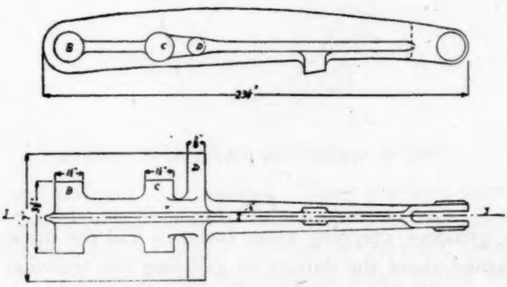

FIG. 7—WEIGHT OF CASTING 16 POUNDS

from blows. However, there would always be a possibility of blows being caused again for the same reasons. The safest way was to put a small riser, about 2½ inches in diameter, on the boss D and this was done, no trouble being experienced thereafter.

Fig. 7—Excessive Grinding

Excessive grinding is a source of considerable trouble in castings shipped out of the foundry. To illustrate such a case,

the casting shown in Fig. 7 has been selected. It was necessary in order to make a sound casting, to put risers on the bosses B and C and on the trunnion D. The trunnion D being of small diameter, it was difficult to get a riser of any size on it and yet leave a mark or guide for burning and grinding. Out of shipment of 150 castings, 36 were reported as having been ground too low on the trunnion D. No change could be made in the molding method but a note of the trouble encountered was filed with the pattern card. Each time the pattern has come in, the

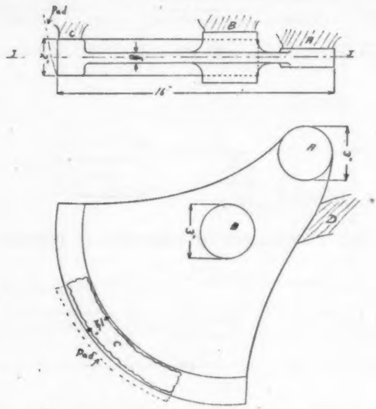

FIG. 8—WEIGHT OF CASTING 46 POUNDS

Fig. 8

burners, grinders, chipping room foreman and the inspector have been warned about the danger of grinding the trunnion too low, with the result that no more castings have been reported as having the same trouble as that met with at first.

Fig. 8 shows a casting which is an example of how unwillingness of the machine shop to remove a little stock from a section of the casting where finish is not called for can result in added delay and expense for both foundry and machine shop.

The job was molded as follows:

7 inch by 4 inch by 9 inch high riser at C—Joint on JJ—Gate at D.

5 inch by 9 inch high riser at B.

4 inch by 9 inch high riser at A.

The first trouble appeared in the foundry. This was a shrink hole exposed by cutting of the riser and grinding at B. To remedy this five chill nails were placed under the riser to accelerate the cooling of the boss B. This measure proved effective, and the castings were shipped out.

The next trouble appeared in the cutting of the gear teeth in the outer section of the casting coming under the riser at C. If it had been permissible to pad the riser C out over the webb instead of restricting the riser neck to the width of the gear teeth blank it is probable that no trouble would have been encountered.

Thirty per cent of the castings shipped were found defective

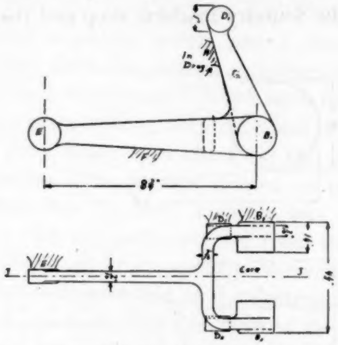

FIG. 9—WEIGHT OF CASTING 11 POUNDS

in this way and had to be welded. Three per cent were rejected. When these rejected castings were made over the blank for the gear teeth was padded below the riser as indicated on the sketch in Fig. 8. These castings also showed small shrink holes when the teeth were cut but were welded and used. A note of this fact has been filed and on the next order an additional step will be taken to prevent this shrinkage. Nails will be placed in the gear teeth blank. It is admitted that this is not good practice, but as it is not permissible to pad the riser C in over the webb, no other method has yet been devised to cure the trouble.

Fig. 9—Another Sample of Blow Hole Troubles

The castings shown in Fig. 9 is another example of the danger of trouble from blow holes, even though the shrinkage

problem has been amply taken care of. At first this casting was molded as follows:

Joint on JJ—Green sand—Gate at F (on joint).
3 inch riser at B, and D.
3 inch riser at E,
3 small chill nails in B-2 (bottom of mold and under core).
3 small chill nails in D-2 (under core).

For a while the castings made this way were sound, but at last a report came through of large blow holes found while milling the bosses D_2 and B_2 which had been located in the bottom of the mold, and chilled. The blow holes were so bad that the casting was taken into the foundry machine shop and the arm G to which

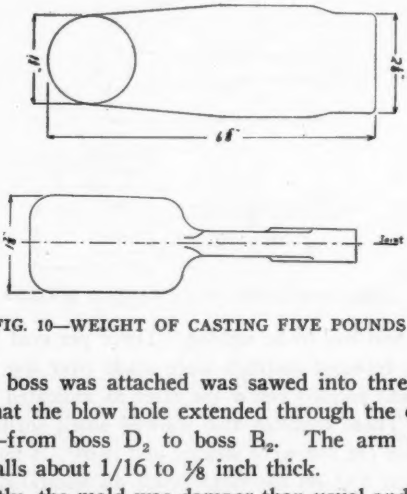

FIG. 10—WEIGHT OF CASTING FIVE POUNDS

the defective boss was attached was sawed into three pieces. It was found that the blow hole extended through the entire length of the arm—from boss D_2 to boss B_2. The arm was a mere shell, with walls about 1/16 to ⅛ inch thick.

Apparently, the mold was damper than usual and the unusual amount of steam generated was trapped in the lower part of the mold, having no chance to work its way out through the sand before the metal set.

To remove the possibility of a recurrence of this trouble the molding method was changed so as to be as follows:

3 inch risers at D, B, and E.
Gate at A (in drag).

⅛ inch whistler carried through core from boss D_2 to D_1.
Riser carried through core from boss B_1 to B_2.
3 small chill nails in boss D_2 (in bottom).
3 small chill nails in boss B_2 (in bottom).

It may be noticed that in using this method, no blind passages or traps are left in which gas or steam may be cornered, there being an exit for steam and gas at every extremity of the mold cavity.

There has been no trouble of any kind experienced with these castings since the latter method has been in use.

Fig. 10—Trouble from Shifting

Fig. 10 shows a casting which caused trouble from shift. It is a peculiar case, since the pattern equipment and flask equipment was first class in every way. There were four half patterns on a plate, the one plate making both cope and drag.

Two molds were made as a check on the mounting of the patterns on the plate. The castings showed no perceptible shift. An order of some four hundred castings was then made and shipped. Later, a complaint was received from the machine shop to the effect that about half of the castings received were so shifted as to interfere with their insertion in the drilling fixture.

We were at a loss to explain the cause of the shift, but upon investigation it was found that the molder closing the molds had used a short pin instead of a long one. The short pin passing through only the two adjacent pin holes of the cope and drag flask, at the joint, permitted an appreciable wobble or skewing of the pin, resulting in a shift. The sample which had shown the pattern to be properly mounted was made, using long pins to close with. With the long pins passing through four pin holes—in the top and bottom flanges of both the cope and drag flasks—no wobbling or skewing of the pins was possible and any shift due to the clearance of the pin in the hole would be imperceptible.

Fig. 11

Fig. 11 shows a casting, many of which were rejected before a method was found which produced consistently sound castings.

To begin with, the design of the casting was such as to make it very difficult for the foundry to get the bosses BB sound. It

can be seen that these bosses BB were unnecessarily heavy as compared to the arms YY or vice-versa.

The original molding method was as follows:

Joint on line JJ—Large gate at A, fed by 4 inch sprue 9 inches high.

½ inch chill rod passing through center of bosses BB.

⅛ inch whistler up through cope from bosses BB.

This method produced very blowy castings. It was thought that the light arms YY set before the gas, steam, or air pocketed in the bosses BB could be forced out through the whistler. Permission was obtained from the engineering department to increase the thickness of the arms from 7/16 of an inch to 9/16 of an inch, not enough, but it helped.

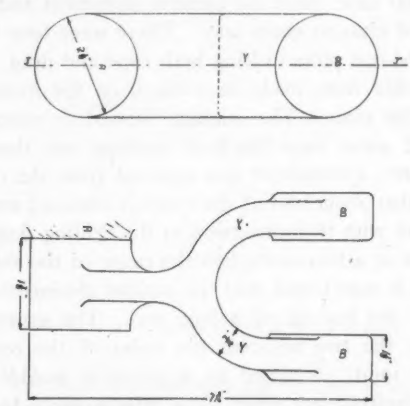

FIG. 11—WEIGHT OF CASTING FIVE POUNDS

The same method was used in making the molds after the pattern had been changed to conform to the new design as was used in the first case, except that a ¼ inch whistler was used instead of a ⅛ inch whistler. The castings made this way were explored and large blow holes were still found in the bosses BB. The arms YY were still freezing and preventing the entrapped air and steam from being forced up through the whistler.

It was thought that additional pressure in the mold would force the entrapped air and steam out through the whistlers more rapidly, and thus possibly fill the bosses BB with metal before

the arms YY set. Accordingly, six inches more height was put on the sprue, making it 15 inches high. This produced the desired result. Four castings made in this way were explored and found to be sound. Out of the next shipment of two hundred castings, none were rejected, and it was necessary to weld only six.

Defects Discovered in Foundry

The original plan of this paper, as it was assigned, was to cover defects after shipment. Another paper was to cover defects found prior to shipment from the foundry. Inasmuch as the A. F. A. *Bulletin* of June, 1926, contained no reference to the latter paper, the author may be pardoned if he touches on this phase in a general way.

Reference to the tabulation of losses during 1923, 1924, 1925, and first six months of 1926, shows that about fifty per cent of the condemned castings are discounted in the foundry and fifty per cent rejected in the machine shops. These discounts in the foundry for a three-month period this year have been tabulated above in Table 8.

Table 8

DISCOUNTS IN STEEL FOUNDRY

Second Quarter, 1926

	Cause	Per Cent by Weight of Cast		Cause	Per Cent by Weight of Cast
1.	Dirty	0.508	14.	Pattern wrong	0.041
2.	Cracks	0.495	15.	Shake out (tears, etc.)	0.036
3.	Slag	0.491	16.	Core wrong	0.030
4.	Shift	0.402	17.	Broken in handling	0.013
5.	Blow holes	0.304	18.	Strained	0.005
6.	Shrinkage holes	0.291	19.	Core omitted	0.002
7.	Cold metal	0.256	20.	Misplaced riser	0.002
8.	Scabs	0.169	21.	Run out	0.001
9.	Diaphragm blades burned	0.123	22.	Flask closed wrong	0.001
10.	Core set wrong	0.070	23.	Cope raised	0.001
11.	Crushed	0.065	24.	Loose pieces omitted	0.001
12.	Grinding	0.048			
13.	Burning	0.045		Total	3.400

The Schenectady works steel foundry is probably neither better nor worse than most foundries producing similar work under similar conditions. The castings range from several to the pound, up to ten tons. The metal is produced in two basic lined electric furnaces. Ladles are all bottom-poured.

While we have always appreciated the fact that bottom-pouring is not the best method for small molds and small castings, we have been very reluctant about changing one of our furnaces over to an acid hearth and using the metal from it in making small castings, pouring from either small bull ladles or shanks.

However, this past few months has witnessed the installation of sorting and tabulating machines in our foundry office, whereby we are able to obtain quite readily and quickly individual costs of castings from every pattern. We are also able to sort and tabulate a great deal of information for statistical purposes, which would have been impractical before. Some of the tabulations made have shown us that we can no doubt afford to have two melting and pouring practices within the same shop. As things now stand, one of these furnaces will soon be lined up with an acid hearth and all small castings will be poured from small bull ladles or shanks.

By analyzing Table 8 we find certain appreciable causes which are directly or indirectly due to the sand being improperly dried, in the ovens, sand too wet, or poorly vented. We have designed and have in operation a large car type mold drying oven which uses preheated, circulating air, with this air kept high in humidity at the start, but gradually decreasing as the temperature increases.

This gives our dry sand work a very excellent mold surface, and we obtain a superior casting from molds dried in this particular oven. As soon as possible our other two mold ovens, now of the usual oil-fired type, will be changed over to this new design.

Facings

Facings for both green sand and dry sand molds are prepared in muller-type mixers, and are of proper moisture content as they leave the mill. However, it often happens that a box of sand is left over night or over the week-end improperly protected from air-drying. The molder sometimes proceeds to temper it to suit his taste and often gets it too wet. Proper supervision is the only remedy we know of in this case.

Cracks

Considering the type of castings produced, we believe our losses due to cracks are fairly within reason. We try to bracket

angles and changes in section judiciously, realizing that it costs money to remove these brackets afterwards. Of the losses due to cracks, we believe a rather minor percentage is due to the quality of the metal.

We note 0.4 per cent of the weight cast was discounted due to shifts. This is partly due to a certain percentage of flasks that should be kept in better repair; and also due to the closing gang being careless, using a short pin where a long one should be used; sometimes due to removing the pins before clamping the job; sometimes, but infrequently, due to worn dowels in the split, loose pattern jobs.

Shrinkage Holes

Approximately 0.3 per cent was discounted due to shrinkage holes, either becoming apparent adjacent to intersections, or beneath a riser after it is removed and the pad ground down.

As a general thing, the larger steel castings show a very small percentage of losses, either in the foundry or machine shops, due to shrinkage holes. In the case of smaller and medium sized castings, however, it's a continual battle to keep these losses down. Some of the cases have been shown elsewhere in this paper. We know of no gilt edge rule to follow to overcome these losses, we simply have to treat each casting as a separate problem.

Cold Metal

We could probably show lower losses due to cold metal, but the great difficulty we have is pouring off so many heavy and light castings in the same heat. While we endeavor to avoid doing so, it's not a clean cut division by any means.

Item (9) nine in Table 8, pertains to nozzle diaphragm partitions for steam turbine work, and is not of general interest to foundrymen, as this class of castings would only be made by few foundries.

Defective Core Setting

Setting cores wrong is usually avoided by the use of tell-tales on core-prints. However, a job gets into the shop now and then

without these proper precautions having been taken, and a number of bad castings will be made. Under this same heading comes certain cases wherein the man setting the cores must have been thinking of anything but the work at hand.

Crushes

Under crushing we can find a number of reasons: poorly secured cope, i. e., insufficient bars, gaggers, etc.; cope not sufficiently rigid to withstand handling; bottom board or plate too weak and not resting on a proper bed; cores not setting in mold properly; in the case of dry sand, failure to shave the joint properly, or otherwise protect the joints from touching too hard when closing up the mold.

Grinding and Burning

Under grinding and burning we have certain aggravating losses. With each man in the cleaning room working piece work, the men burning off gates and risers find their fellow workmen who are chipping and grinding use rather pointed language if the cutting is not done very close to the mark. This often results in the riser or gate being burned too close, with consequent loss of the casting. Here again is wide awake supervision required.

It may be interesting to note the small percentage of loss due to pattern being wrong. This is a direct result of careful checking of patterns before they pass into production.

The various remaining causes of discounted work in the foundry are shown in Table 8, and are practically self-explanatory.

More Knowledge of Losses Needed

The main object of this paper, however, is to show, possibly, the necessity for more and better knowledge of the losses after shipment, particularly those losses which the machine shops have to carry in their expense distribution. With a selling price equal to his competitors, that foundryman best aware of the above losses, what they are in order of their importance, and how to overcome them, will get the business.

Discussion

Major R. A. Bull: Mr. Chairman, I would like to say that I think Mr. Sampson is entitled to congratulations on two points, first, on the fairness with which he is analyzing the defects in his foundry through the study of this excellent statistical information, and second, on the success that he and his associates have evidently had recently, or in the past two years, I believe, in talking the engineers of his organization into a more sensible frame of mind. I have been very much interested in reading this paper before it was presented and in noticing the extent to which analysis is made by Mr. Sampson covering all these defects. I think there is no doubt whatsoever but that it requires just this sort of thing to point the way to a lot of investigations in the foundry which have a thoroughly practical basis and the following of which will bring probably greater returns in dollars and cents than any other particular form of investigation we can prosecute.

J. L. Blair: Mr. Sampson talked about foundry inspectors, and I would just like to ask him if he means inspectors on the cleaning floor or were they on the molding floor?

J. M. Sampson: In some cases on the molding floor and in some cases on the cleaning floor. This paper, however, refers largely to the inspectors on the cleaning floor.

J. L. Blair: Another point was on this Fig. 1. The weight of the casting is given as 32 pounds and he talked about chilling the center of the boss there and putting a riser on top of it. I would like to know just what defect appeared there. Was it cracking?

J. M. Sampson: No, a shrink cavity.

E. R. Young: I would like to ask Mr. Sampson what their practice is with regard to the preparation of internal chills to avoid rust.

J. M. Sampson: I think the first time I saw horseshoe nails used as internal chills was at the plant of the Michigan Steel Casting Co. in Detroit, under the regime of our old friend Hiram Neal. At that time they were regular horse nails, but finally a nail was developed with a very large head. These we buy and copper plate in our own plant. It costs us about one-third of a cent per pound of nails to copper-plate them. This prevents rusting, but does not prevent condensation of moisture on them, especially with green sand work.

About one-third of our work is green sand, one-third dry sand, and one-third green sand drags and dry sand copes.

Due to condensation of moisture on these internal chills, defects can occur from the kick off from these chills. We would like to be able to get along without using these chills, however.

CHAIRMAN J. H. HALL: The practice that Mr. Sampson follows in his foundry in the use of chills to accelerate the cooling of portions of the casting is to use horseshoe nails, internal chills. And, as perhaps some of you know, I was rash enough to state in print a few years ago that the use of horseshoe nails could not be sufficiently discouraged. I have gotten some hard wallops under the ear for having made such a statement in print, but I still stand on it.

In running through this paper I notice that in the majority of the cases blowholes or cavities of some kind coincided with the place where the nails were, which looked to me as if there was some cause and effect between the nail and the hole.

In our own shop it was formerly the practice to use nails to a tremendous extent—I am talking of our plant at Easton, not our plant at Highbridge—and I know of one particular casting, a small frog used in the track in mines, where it seems to me we must have used a carload of nails a year in chilling certain places to make them sound, and around those nails there were always holes of some sort. We discontinued the use of nails and went over to the practice of quite heavy external chills placed in the mold. We salvage those chills, and as we don't use them, we save the cost of nails, and we have never had a single casting since with any defect at that place where a chill is necessary.

C. J. JERNSTROM: I have had quite a lot of experience with chilling with horseshoe nails for a number of years. Since I came over to Riverside, I found I had to discontinue it. Although we have been able to make castings sound so far as freedom from shrinkage holes is concerned, employing nails, I found when we put pressure on it that it leaked almost all the time through those nails or at the side of the nails. In order to overcome that we had to employ oversize chills or larger heads, and I could not agree with Mr. Sampson there with regard to using horseshoe nails for that particular purpose.

Then, there was another thing that I wanted to ask particularly. Mr. Sampson mentioned that the castings that showed defects in the foundry were not permitted to be welded but were sent to the machine shop and welded up there. How do you take care of that? That would be impossible for a foundry making castings for commercial uses, because our expenses would be too high. When we see a defect we absolutely have to weld it and anneal it before we send it out.

J. M. SAMPSON: I tried to make it clear at the start that our practices at Schenectady are different from the average steel foundry. About 20 per cent of our output is shipped to our West Philadelphia Works. When they had any welding to do, the castings had to be annealed there, and their annealing facilities were very inadequate. It was this condition that largely brought about a change in our policy, and that now permits us to do welding prior to shipment to West Philadelphia.

I also want to bring out this fact, as the Chairman of this meeting points out, that we have considered internal chills, such as horse nails, something of an evil. Their use enables one to "get by" with certain castings—that would be too expensive otherwise.

But so far as being desirable, I agree with Mr. Hall; one cannot introduce a foreign material such as a nail into a casting and have as good a casting as when that nail is not present. providing the space occupied by the nail is taken by good sound cast steel. We are eliminating their use as much as possible. We use external chills to a considerable extent, but do not altogether like the surface produced on the castings.

There are many sections of innumerable castings that cannot be fed naturally from a riser, one has to take care of it, either with an internal or external chill. Many times we resort to water cooling the sand adjacent to the "hot spot."

In our high pressure castings we avoid using internal chills.

LEON CAMMEN: I wonder if an opinion of a man who is not a foundryman would be of any value. It seems to me that a good many troubles with castings are due to two main causes. One has been pointed out by the first speaker, and that is their unsatisfactory practice. The other has not been pointed out at all.

Now, in the matter of practice I can't see for the life of me, and I am buying quite a few castings for myself and companies for whom I am acting as consulting engineer, why the foundries dislike to make the patterns themselves. The average jobbing foundry does not want to make patterns; they prefer, in some cases they insist, on the pattern being sent to them by the customer. Quite often the customer knows absolutely nothing about the way of designing the casting. The result is that the average foundry practically insists on having trouble, and whoever looks for trouble gets it.

I had quite recently this illuminating experience. A certain company was making castings of monel. Then they decided to try out steel, and as they had the patterns, they sent the patterns to the foundry. Well, patterns for monel are not designed exactly as for steel. The result was that the steel castings were bad. Now, if the foundry knew about it, they would probably have the sense to ask for it, but they have the patterns. Certain companies already have seen the light and they are insisting on either having the patterns made themselves or approving the patterns. and that would be the only proper way.

Now, another point. In the second question I believe we are getting on very dangerous ground. As an outsider, I will probably be told that I am speaking about the things that I know nothing about, perhaps, but the thing I have in mind is this. I am referring now exclusively to open hearth foundries and to foundries using comparatively small open hearth furnaces, say below 20 tons. Now, what I would like to know is, can

anybody here, or outside, tell us, tell me, just what we know about melting steel in the small open hearth furnace? Now, we know quite a lot about melting steel in a big open hearth furnace, say 100 tons, but quite often when we melt steel in a 50-ton open hearth furnace we begin to run into trouble which we don't have in the 100-ton open hearth furnace, or the 75-ton. Then, when we come down to a 10-ton furnace, I find this, that not a single investigation is available, except those of a long time ago, as to what the conditions of the steel are, how this steel is brought up, and so on, in a small open hearth furnace. There is not a single investigation that I know of that is worth the paper it is printed on as to the slag in the small open hearth furnace, and as to what this slag will tell us. There is not a single investigation as to the reactions between the steel and the oxide in the open hearth furnace, in the smaller open hearth furnace. We know about it in the big open hearth furnace but we don't know a thing in the small open hearth furnace. And we know that in metallurgy the mass effect has a tremendous importance. We know, theoretically, that the 10-ton open hearth furnace does not work in the same way as the 100-ton open hearth furnace.

Now, it is my sincere conviction, and, as I say, most of you will tell me that I don't know what I am talking about, that in the small open hearth furnace you are not making the steel but you are simply throwing certain materials into the furnace, putting on the heat and getting what the gods of luck will bring you. I believe that the American Foundrymen's Asssociation would do a tremendous service to the industry if it should start a line of investigation of what happens in the small open hearth furnace, and if it would work out some simple test by which the condition of steel in the small furnace could be determined.

Chairman J. H. Hall: There are probably a great many of you here who can tell the last speaker why foundries insist on having trouble in the foundries with their patterns, and I know that there are gentlemen here who are aware of what happens in a small open hearth furnace. I think it is true that there is not much in print about what happens in a small open hearth furnace, but I think there is a whole lot of knowledge in the foundries, or they wouldn't make as good castings in them as I know they do.

J. M. Sampson: Are you referring to basic or acid open hearth?

L. Cammen: I am referring to both, but acid particularly, because on basic we have an enormous amount of information as to the big furnaces in this country. As to the acid we know comparatively little about the big furnaces.

J. M. Sampson: I dare say there are men in this room capable of producing very good steel in small acid open hearth furnaces—at least in furnaces of from 15 to 25 tons capacity.

The general characteristic of slags produced when making such steels are comparable with those found in the Creusot Works in France, or the Midvale Steel Company at Nicetown, Pennsylvania. Many plants can produce a very superior cast steel, but it is largely a question of operating costs, because it certainly takes a lot of additional time.

R. S. MUNSON: I would like to reply to Mr. Cammen. He commented on the foundries seeking for trouble by insisting on the customers making their patterns. We have insisted a great many times on having the customer allow us to make their patterns. The trouble with a great many customers is that they have their own pattern shops that they like to keep busy; they like to make their patterns according to their own ideas of pattern making and disregard the foundry entirely. I think all you gentlemen will bear me out in that, that you have had many times the difficulty presented of the customers insisting on making the pattern in their own way, particularly railroad customers.

As to the matter of steel in small furnaces, I am not a metallurgist. Mr. Hamilton of the American Steel Foundries has a paper to be presented at this convention in regard to open hearth slags which I think answers some of your questions pretty well. I don't know whether Mr. Hamilton is here or not, but that paper will cover the study of open hearth slags in small furnaces, that is, furnaces of 25 tons and under. I have been connected with foundries that made steel castings from 60-ton furnaces, and it is my personal opinion that steel made from furnaces of 25 tons or under is superior to the steel that is made in the large furnaces. We have just as good ideas—my particular company has a 10-ton open hearth furnace and we pride ourselves that we make just as good steel, physically and chemically, as anybody in a 25, 35 or 40-ton furnace. Our physical tests bear it out, our chemical tests bear it out, and I don't think you will find any foundryman who operates a small open hearth furnace who is willing to admit that he doesn't make steel just as well as they make it in the larger furnaces.

MAJOR R. A. BULL: Mr. Chairman, I believe one reason for the fact—and I think it is a fact—that the average steel from open hearth steel made in the small furnace is better than the steel made in the large open hearth furnace is because by the very nature of the case the large open hearth furnace produces metal to be forged or rolled, and the opposite condition, of course, is true with respect to the small melting unit, the product of which is used for castings. I think there isn't any doubt that steel that is made for castings in the open hearth or in any other process is more thoroughly degasified, more thoroughly cleansed, than the ordinary steel made for mill purposes.

E. R. YOUNG: I might add a little bit to what Mr. Sampson said, that it is pretty largely a matter of cost as to how far the jobbing foundry

can go in making what might be called the Midvale type of steel, using the Midvale practice.

In 1920 they got a lot of publicity on their method of making acid open hearth steel, and, as he says, they make a very fine product. I am concerned with our practice somewhat and have had occasion to investigate the practice of some of our competitors, and I think the average foundry, or maybe I shouldn't say "average," but a good many of the foundries making steel in 20-ton open hearth are using some modification of the Midvale method, they are taking as long to heat it as they can afford to, considering the product they are making and the requirements of that product.

The American Steel Foundry Industry

Comments on Its Past Developments, Its Present Tendencies, and Its Future Possibilities

By R. A. Bull,* Chicago.

The Pioneers

It is a pleasant pastime for some who trace their ancestry back to the days when pirates were regarded as gentlemen, and when conduct was not so much a matter of ethics as of expediency, to patronizingly decry America's lack of seasoned culture. It seems to be an equally agreeable occupation for some who consider themselves as solely responsible for their present comfortable stations in life, to proclaim the fact that they are self-made. The members of the aristocracy often undervalue the priceless virility behind a single generation's achievements, while the newly rich frequently fail to appreciate the wholesome maturity resulting from the training of former generations.

The story of steel in the United States is a striking illustration of the fact that ours is a young nation, and of the more important fact that America's development has been largely due to the driving stimulus that characterizes immaturity. This is as true with respect to industry as to the arts and letters; and the manufacture of steel presents no exception. Only within the last few years have Robert W. Hunt and Joseph S. Seaman gone to that final resting place which we may hope is reserved for the pioneers who made important contributions to our economic progress, in manufacturing steel products. Many now actively engaged in industry enjoyed personal acquaintance with each of these men; the one, Captain Hunt, having to his credit the rolling of the first steel rails made commercially in the United States; the other, "Daddy" Seaman (later to become a prominent

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and peculiarly beloved foundryman), sharing the honors due Captain Hunt through having turned the rolls employed for making the original steel rails in 1867. The metal was produced in this country in a Bessemer converter almost coincidentally with the perfection in Europe of the open-hearth furnace.

The year that marked the beginning of steel rail manufacture in America has another important event to make it industrially significant. Probably the original steel castings made in the United States were then produced in what was known as the William Butcher Steel Works, which later came under the control of the Midvale organization. Among the first steel castings made at the Butcher foundry were crossing frogs for the Philadelphia and Reading railroad. It is claimed that these castings were so satisfactory that some of them were in use for 37 years, until 1894.

Unfortunately in the steel, as in other industries, those who accomplish most are not inclined generally to leave behind them comprehensive chronicles of their achievements. The story of the life of many a man who materially helped promote progress in an important branch of science, engineering or industry would provide a record of great interest. It is difficult to imagine a more fascinating story than the autobiography that might be written by John Hayes Hammond, dean of American mining engineers, now in his seventies, and continuing a highly useful career that has had many dramatic episodes. It will be a misfortune if Mr. Hammond eventually does not find the time and feel the urge to leave a written record of his life and observations, full of interest for all those who, in making their living in what some narrowly regard as industry, serve the human race by making the world a very pleasant place in which to live.

There are examples other than that of Hammond's career which could be cited readily to demonstrate the breadth of observation coming within the viewpoint of a progressive, experienced follower of any modern major industry. Illustrations are found often in the historical references to the making and casting of metals. The achievements of Reaumur, Huntsman, Boyden, Bessemer, Siemens, and others who have joined their fathers,

have left for us not only inspiring records of metallurgical significance, but transcripts of events having much human interest even for those who, because of detachment from the activities directly or indirectly related to mill or foundry, might imagine a recalescence point to be some kind of sharp instrument; or the drag of a flask to be a phrase indicative of present day habits for which intolerant reformers are responsible. The steel foundry has had its pioneers whose experiences are of interest from many standpoints. Few of them have left chronicles of their activities. It is regrettable that old-timers now deceased, like Wharton, Johnson, Taylor, Eagan, Gallagher, Harrison, Deutcher, Geo. H. Smith, and others, were not generally of the type likely to sit down quietly in their placid days of ripened retrospection and record for those of a younger generation the events associated with the beginnings of the steel foundry industry in the United States. For, created sixty years ago, it has had a highly interesting development, largely dependent on concurrent progress in several industries, and essentially contributory to advancement in many. There are living, many individuals who have made during long careers, either through themselves or through the work of their subordinates, numerous important contributions to one or more phases of the steel foundry industry. Among these men are John Maher, W. D. Sargent, J. C. Davis, I. W. Frank, C. C. Smith, S. P. Bush, W. H. Worrilow, and C. H. Howard. Some of these men are well qualified to describe important facts concerning the industry's advancement. Generally, such individuals get much more satisfaction from doing things than from writing about them.

The writer wishes not to become tiresomely reminiscent in speaking of the earlier days of the industry. He believes even a brief analysis of the development of any mechanical process or combination of processes lacks an appropriate feature if shorn of references to individuals who have made important contributions to its progress. It has been logically claimed that the future of an industry cannot be reasonably forecast without the most intelligent analysis not only of present conditions but of circumstances that have been factors in creating and maintaining the existing situation. The purpose then in referring to the earlier

days and to the individuals who were prominent in the industry during significant periods of growth is to establish such relationships as may be helpful for intelligent consideration of present and prospective conditions.

Progress During the Nineteenth Century in Open Hearth Foundries

The history of the steel foundry industry in America for the first 20 years of its existence is not now of particular interest. Many of our manufacturing operations were then in a state of flux. Steel founders were cautiously feeling their way. The nation had not yet become an economic giant. Developments in the manufacture and distribution of steel castings were more or less sporadic until about 1887, when the successful production of steel rolls and certain castings for ordnance use directed the attention of many who foresaw the application of the product of the steel foundry to a large variety of uses. Before the last decade of the 19th century, the industry reached the adolescent stage and became an important factor in our country's economic development.

In the interesting period now facetiously termed the "gay nineties," steel casting manufacture made an important advance step by the successful adaptation of green sand molding. Looking back and considering the striking effect this development had on the industry, it seems peculiar that information regarding green sand molding in the steel foundry was somewhat slow in coming to the notice of those in the technical world who betrayed interest in, while not associated with, steel casting manufacture. In 1909 the writer clipped from a technical journal that was then and is now well known, an article in which a consulting engineer of high reputation stated: "For steel castings the molds * * * must be thoroughly dried before the hot metal is poured in them, * * *. To pour the hot steel in molds filled with green sand that has not been dried out would cause the gases to form so suddenly that they would cause an explosion."

Pioneers in the middle Western states were largely responsible for the development to which we are referring. Probably

it was the principal factor in the very rapid adaptation of cast steel to railway use, which was to become extensive and permanent. Green sand molding did much to solve the problem of shrinkage, which had been an extremely troublesome factor in producing many castings, the designs of which presented difficulties with respect to the contraction of cast steel during solidification, excessive as compared with that of other ferrous metals. The result was among the most important epochs in the industry's development, through the establishment in the last few years of the 19th century, of large open-hearth shops for the specialized production of railway steel castings. There was economic justification for erecting these foundries, the number of which, and particularly the combined capacity of which, increased greatly during the period we are considering. In many respects, the 10-year interval beginning with 1895 can be regarded as of the highest importance in plant development for steel casting production. An innovation that was applied at this time with great advantage to many steel foundries was the use of fuel oil in open-hearth furnaces. This eliminated certain difficulties from red-shortness caused by sulphur from inferior coal used for producing gas. There were other advantages derived from the liquid fuel which have been of material benefit in many foundries.

Most of the railway specialty shops from the beginning adopted the basic lining for their furnaces, primarily because of the cheaper operating cost as compared with the expense of making acid steel, which continued to be favored among the Eastern foundries, where the product consisted, to greater extent than in the West, of castings requiring extensive machining before application. In the nineties and at the beginning of the present century, there were restricted opportunities afforded the steel maker for satisfactorily deoxidizing his metal. The result was a relatively large percentage of steel castings containing blow-holes, particularly in the product of the basic furnace, where the oxidation process is necessarily prolonged as compared with the operation of acid lined furnaces. For some time the only alloy given the name of ferro-silicon which was commercially available, was one containing usually from 12 to 13 per cent

silicon. Carborundum or carbide of silicon was extensively used as a supplementary deoxidizer. It contained approximately 60 per cent silicon, 35 per cent carbon, 1.5 per cent iron, and 1.5 per cent aluminum. Restricted opportunities for uncontaminated deoxidization naturally resulted in too great dependence on aluminum, which was introduced frequently in such a way as to materially reduce the shock resistance of steel castings.

Relatively poor ductility generally characterized steel as produced for castings at the beginning of the 20th century. The writer has records of the performance of a basic open-hearth foundry that in 1900 was well regarded, and produced common steel averaging .28 per cent carbon, which, after a normalizing treatment, showed usually a tensile strength of 70,000 pounds and an elongation in 2 inches averaging 8 per cent. Such metal would not be acceptable today for most purposes employing cast steel.

The ductility values typical of acid open-hearth steel made at the close of the 19th century generally were higher by a small margin than those obtained in basic practice, but were far below the figures prescribed today. At that time, when steps were being taken to organize the American Society for Testing Materials, specifications for steel castings usually did not include requirements for reduction of area. The percentage of elongation was regarded by most engineers as sufficient indication of ductility. Engineering handbooks and copies of specifications published 30 years ago show a prescribed minimum tensile strength of 60,000 pounds and a required percentage of elongation which did not exceed 15 per cent and in many cases was as low as 10 per cent. Values for yield point and reduction of area were not prescribed. The progress of the industry during a quarter-century of development can to some extent be gauged by a comparison of the requirements just mentioned with those prevailing today, which provide for soft steel castings averaging at least 60,000 pounds tensile strength, an elongation of not less than 24 per cent, and a reduction of area of at least 35 per cent.

The melters in charge of steel furnaces at the beginning of the present century and for some years thereafter were not

responsible for all of the relatively poor showings of tension test pieces, most of which met the easy requirements of earlier specifications. There was deficient knowledge of heat treatment, by which term is now generally meant normalizing, annealing, or any other application of heat, single or repeated, for producing structural refinement. There was inadequate attention given to the accurate machining of test specimens, properly regarded today as a highly important factor. Tool marks on the finished throats of tensile test pieces were seen frequently, and often escaped criticism. It would be impossible to intelligently estimate what the tensile properties of cast steel as customarily made a quarter-century ago would have been, if skillfully heat-treated and tested. The melter's associates in the laboratory had much to learn regarding the procedures for developing by heat treatment the latent properties of the steel, and for evaluating the material by means of properly tested specimens.

Irrespective of the responsibility for comparatively poor results, it was ultimately recognized by intelligent consumers that they had not, during practically three decades, been supplied with steel castings whose homogeneity and ductility conferred on the product qualities making it sufficiently dependable under severe service conditions. Realization of the necessity for improvement, at the time referred to, did not place steel castings in a conspicuously unsatisfactory classification as to serviceability. Practically every kind of iron or steel product was embraced in the all-inclusive category of material capable of being more skillfully manufactured, and of being tested with due regard for the characteristic properties of the product when made right. Steelmakers and users began to cooperate in the analysis of data regarding metal made under different conditions, about the time when the American Society for Testing Materials was chartered in 1902. Thus did the inauguration of standardized testing work give the steel casting industry, like others, an invaluable stimulus that has prevailed without interruption, and will continue, without doubt.

It has been pointed out that the manufacture of steel castings in the United States reached the important stage of marked specialization in the late nineties, through the erection of plants

for producing steel castings in large quantities for railway use. Thus was provided the principal incentive for the construction of basic open-hearth foundries. Special equipment was installed about the same time in numerous shops to be largely devoted to the production of steel rolls and other large steel castings for mill use. The manufacture of rolls inevitably led to experiments with alloys, resulting during the next 10 years in the development of important combinations of the elements for this purpose.

Crucible Steel Foundries

The crucible furnace, since 1899 the least important tonnage division of the industry, has maintained its production with reasonable regularity, considering the important developments with respect to other melting units. The earliest records showing steel casting production which are today considered reliable, do not extend beyond 1898. In that year the tonnage of crucible steel casting exceeded the output of the production from the converter, and was more than 4,000 tons. Ten years later it had practically doubled. The peak was reached in 1912, when slightly more than 20,000 tons were produced. The marked increase in the demand for small steel castings, which assumed a significant aspect about 1905, had its effect on crucible steel foundry production. By 1917 the tonnage of crucible steel castings roughly equaled the output 18 years before that time, after a fairly steady decline that began in 1913 and resulted in the very low output of 736 gross tons in 1921. Last year the tonnage of crucible steel castings was reported as 1,833, or less than 10 per cent of the production 14 years before, when the peak for this branch of the industry was attained.

It has been shown that a relatively small volume of steel castings has been produced in the crucible furnace. The size of the vessel militated greatly against its extensive application. The cost and short life of the crucible presented serious handicaps. The converter, despite its very high melting loss (including cupola) of approximately 15 per cent, proved to be a less expensive operating unit than was the crucible furnace. Important features of the converter were its fair-sized capacity, and frequent

delivery of the finished metal. This vessel has never had an equal from the standpoint of supplying the molding floor with steel in moderate or large quantities at a rate approaching continuous performance.

Converter Steel Foundries

A significant development began about 1905, through the adaptation of the Bessemer converter to the production of small steel castings, previously made in relatively low tonnages. The principal inventor responsible for the modification of the converter was Tropenas, whose experiments in Europe in 1890, in blowing the metal above its surface met with success. The converter, modified as to size and partially as to operation, proved to be one of the most useful devices developed for making steel castings. It solved very satisfactorily the problem of high temperature, which had been a difficult one for open-hearth foundries producing heats usually ranging from 15 to 25 tons, limited as to practicability of high temperatures by the life of refractories, and by construction details that necessitated long periods of shutdown for renewing refractories. Ultimately the applicability of the open-hearth furnace to small steel casting manufacture was aided by the construction of melting units having a capacity as low as five tons, and having regenerative chambers and stacks very liberally proportioned to facilitate the utilization of higher temperatures than were typical of open-hearth furnaces of customary foundry sizes. However, the open-hearth furnace in its essential details was recognized from several standpoints as poorly adapted to the specialized production of small steel castings. The converter took its temporarily commanding position in the industry for that purpose, and maintained it until the development of the electric furnace.

The temperatures possible to obtain in the converter provided metal sufficiently fluid to run the smallest sections preferred by designers of very small parts. Shops employing this melting medium, while in a fortunate condition with regard to the specialized production of small steel castings, found themselves handicapped by high metal cost in competition against open-hearth foundries, when producing castings of heavy weight

or large sections. In this, as in all other similar cases, the melting medium occasionally was used for work to which it was not adapted economically. It began to be apparent that the industry, by the nature of the product, would divide itself eventually into two sections. At times there has been a disposition to minimize the distinct separation of the industry, according to the production of large and small steel castings. Confusion has resulted from the occasional, uneconomical adaptation of fairly large open-hearth furnaces to the manufacture of very small castings; and the intermittent, costly use of converters and electric furnaces of small capacity, in the production of very large castings. The industry satisfactorily splits itself into the two divisions according to the melting equipment utilized by the foundry, irrespective of the proportions of castings wisely or unwisely made.

During the first decade of the present century, the manufacture of small steel castings by the aid of the converter made many inroads on the business previously enjoyed by malleable iron founders; and by the development of new uses for steel castings where the strength of the material was an important factor in connection with preferred lightness of section. Many of these new uses were such as to require, for the sake of appearance, surfaces much smoother and freer from blemishes than were required on castings of moderate and large sizes. This naturally resulted in the specialized development of cleaning equipment for small steel castings. Thus did the ingenuity of the mechanical engineer follow that displayed by the metallurgist. That vital relationship has prevailed.

The successful production of converter steel castings inaugurated applications of the product in a great many important industries. The converter proved itself to be, when properly regarded, not a competitor of the open-hearth furnace, but a very important auxiliary to it for steel casting production. The annual output of converter steel castings increased from less than 4,000 gross tons per year in 1899 to more than 22,000 tons in 1905. By 1910 the tonnage of converter steel castings had grown to a figure slightly under 60,000 tons; and the peak of converter steel casting production was attained in 1918, when more than 160,000 tons

were credited to this branch of the industry. A reduction in output then began, due to the increased popularity of the electric furnace, to be referred to below.

Electric Steel Foundries

Thirty years ago a scientifically trained major in the Italian army chose a location in the Alps for exhaustive experiments to demonstrate his faith in the theories held for many years by eminent scientists, that the electric current could be made a satisfactory source of heat for melting and refining steel. Major Stassano's success in 1899 immediately drew the attention of other experimenters in Europe to this method of making steel. Progress in developing the electric steel furnace was for several years pronounced in France, Italy, Germany, Norway, and Sweden. English steelmakers did not find themselves in a particularly advantageous position with respect to this development because of the topography of their country and the resulting scarcity of waterpower.

It was almost ten years after the electric furnace was demonstrated by Stassano to be commercially a successful method of steel manufacture, when metallurgists began their first experiments with it in America. The United States Steel Corporation had prior to this sent its investigators to Europe to study the operation of electric furnaces, of both the arc and induction types.

The pioneers in making electric steel in this country, mentioned in consecutive order, were the Halcomb Steel Company, the Firth-Sterling Steel Company, the General Electric Company, and the United States Steel Corporation. The first two of these started making electric steel commercially in 1908. It was not long after the announcement of the regular production of electric steel for the fabrication of parts not made in the foundry, when certain steel founders who specialized in small work began to study the adaptability of the new unit to their plant operations. The high installation cost was a factor that made steel foundrymen proceed slowly. An important element of expense in numerous localities then, as in some localities now, was the difficulty of obtaining sufficient electric power at a reasonably

low rate. The first steel casting plant selling its product to other industries, which installed an electric steel furnace, was the Lebanon Steel Foundry, where the regular production of electric steel castings for miscellaneous purposes began in 1912.

As previously explained, there was about this time (1910) a quickened demand for small steel castings. This had materially increased the combined capacity of steel casting plants employing converters. Within three years the output of castings from converters had leaped from a little more than 20,000 to nearly 60,000 gross tons. Meanwhile, largely for their own use, some of the steel companies that had installed the electric furnace primarily for rolled or forged products, began to make a few steel castings. In the year 1908 there are said to have been 55 tons of castings thus produced in this country, and during the following year, approximately 300 tons. By 1912 the output of electric steel castings had grown to more than 4,000 tons, and in 1913 it had reached the figure of 9,200 tons, then amounting to slightly less than 1 per cent of the output of all steel castings produced in the United States.

Without doubt the capacity of the electric branch of the steel foundry industry, during a few years, starting with 1910, was greatly increased by the lively imagination of certain exploiters of the new melting medium, who unwisely but successfully undertook to sell many foundrymen with the idea that the electric furnace is admirably adapted to the manufacture of any kind of steel casting within the weight limit regulated by hearth capacity. Some of these enthusiasts vigorously proclaimed what they might have thought, but what was not, and is not, true, viz., that electric furnaces can satisfactorily produce steel with less attention than is required for the operation of converters or open-hearth furnaces. Apparently a few foundrymen have adhered to these mistaken ideas. A producer of steel castings, at the 1925 convention of the American Foundrymen's Association, stated that less skill is needed for operating the electric steel furnace as compared with the open-hearth or converter. Inquiry should be made regarding the uniformity, ductility, and other characteristics of steel produced, before acceptance of claims that within a few weeks a reasonably intelligent man who never pre-

viously made steel can be graduated as a good electric steel melter. It should be kept in mind that there are good, bad, and indifferent grades of metal produced from every kind of steel furnace in use; and that no process is foolproof, nor capable of satisfactorily functioning according to high standards, without skilled manipulation.

Alloy Steel Castings

It has been mentioned that the increasing manufacture of rolls during the late nineties led to experiments with alloys, which resulted in the development of important combinations of the elements for that special purpose. The discovery of manganese steel by Sir Robert Hadfield in England in 1888 was followed, four years later, by the manufacture of the first manganese steel castings in the United States at the plant now owned by the Taylor-Wharton Iron and Steel Company at High Bridge, New Jersey. This development was without doubt the most important one related to alloy steels that characterized steel foundry operations during the 19th century in this country. The manufacture of manganese steel became a specialized branch of the industry, and the product was found to have superior properties for a number of uses to which carbon steel was poorly adapted.

Manganese steel has been made in crucible furnaces, converters, open-hearth furnaces and electric furnaces. The latter are used for making most of the manganese steel castings now produced.

The study of the performance of steel containing from 13 per cent to 15 per cent manganese, commonly classed as manganese steel, developed the fact that this material was not best suited to some purposes for which carbon steel had been employed unsatisfactorily. This prompted experiments with varying percentages of manganese above the content used ordinarily in the steel foundry but below the amount in what had been called manganese steel. The result was the development, due mostly to John Howe Hall, A. F. A—Whiting medallist, of a very useful group of simple alloys, highly susceptible to scientific heat treatment. These became favorably known about 1915.

It is unnecessary to make detailed references to the developments of cast steel containing vanadium, nickel, chromium, molybdenum and certain other elements that have been employed to greater or less extent in making special products in the steel foundry. The origination of many special combinations has been attended by the perfection of special heat treatments, inasmuch as it is realized that the customary single normalizing or annealing operation does not develop many latent valuable properties in alloy steels.

At the present time experiments are being made to produce alloy steels for castings to withstand very high temperatures and pressures simultaneously and continuously applied in service. This presents the most difficult problem steel foundrymen have been asked by industry to solve.

Organized Cooperation

We have shown that the American Society for Testing Materials was the first national organization to stimulate the steel founder in improving his shop practices, through the co-operative investigation of testing methods, which began in 1900. The American Foundrymen's Association, organized in 1896, failed to draw the serious attention of steel foundrymen as a class to its opportunities for advancing their industry, until about 1911. Interest manifested at that time in the presentation of papers on steel foundry topics prompted a movement on the part of progressive manufacturers of steel castings to utilize the A. F. A. as the logical medium for the interchange of experiences and for the discussion of theories relating to the technical phases of the industry. Without doubt the A. F. A. has been the most effective means for developing co-operation between steel founders, through cordial relationships established between operating executives of competing organizations. Approximately 200 steel foundries are at this time affiliated by membership in the A. F. A.

The invaluable aid to the industry rendered by the A. F. A. as a technical body has been supplemented helpfully by the Steel Founders' Society of America as a trade organization. It was founded in 1902, at a time when the industry sorely needed a

medium for the joint consideration of business problems such as ordinarily engage the attention of trade associations.

Other organizations and institutions whose activities have national significance, which have been helpful in one or more ways to steel foundrymen, include the following: American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, Society of Automotive Engineers, American Electrochemical Society, American Society for Steel Treating, American Welding Society, American Iron and Steel Institute, National Research Council, U. S. Bureau of Standards, U. S. Bureau of Mines, and the U. S. Division of Simplified Practice.

In thus giving credit to national organizations and government departments for the assistance they have rendered the steel foundry industry, it is appropriate to mention the benefit derived by American steel founders from the activities of the Iron and Steel Institute chartered in Great Britain, but having a membership of international character.

It is no longer necessary to emphasize to steel foundrymen the benefits from co-operation. Probably the future will see numerous collective efforts by competitive manufacturing plants, each such instance of co-operation being intensive, and characterized by a relatively small number of participants, employing substantially the same major processes and making similar specialized products. Such smaller co-operative organizations promise to reflect the extent of specialization in the industry.

Capacity and Output

The steel foundry industry as a whole, without exception of any of its divisions or subdivisions, was vigorously stimulated because of and during the World War. It is unnecessary at this time to elaborate, although it might be advisable 50 years hence, on the enormous variety of needs for steel castings which directly and indirectly grew out of the war. It so happened that previous to the war demands that followed the entry of the United States into the conflict, the production of steel castings was at a sluggish rate. This is illustrated by the total output of slightly more than a million tons of steel castings in 1913, followed the next year

by a production of less than 700,000 tons. During each of the critical wartime years of 1916-17-18, the output of steel castings in this country remained fairly stable at a figure roughly averaging 1,400,000 gross tons. The peak of wartime production was reached in 1917 when 1,441,000 tons were made. To date the industry's record output exceeds that figure by a very small margin. The maximum demand of 1,458,000 tons was supplied in 1923.

The expansion of the steel foundry industry in America, caused by the war, proved to be uneconomical. Many foundries were built or enlarged. The expectation of obtaining, before the declaration of peace, a sound financial foundation for subsequent operations presented to some, such an alluring prospect that they gave inadequate consideration to the varying shrinkages of demand which would immediately follow the cessation of hostilities, which would attend industrial reconstruction, and which would characterize peace-times. Today the chief handicap of the industry is the enormous combined capacity for producing steel castings, gauged with relation to the developed needs for the product.

Comparative data illustrating the point just made are obtainable from recently published statistics. Within the last few months the American Iron and Steel Institute, following the careful accumulation of authentic first-hand information, published the latest edition of its Iron and Steel Works Directory. When we tabulate the data found in this book, which is the most reliable single source of information on self-estimated steel works capacity available, we find some very interesting facts. The yearly capacities of the various branches of the industry, expressed in gross tons of output, as summarized by the writer from the data in this publication, are as follows:

Acid Open Hearth	939,607	
Basic Open Hearth	909,385	
Total Open Hearth		1,838,992
Electric		593,541
Converter		148,550
Crucible		3,730
Unclassified		27,500

These figures show a combined annual capacity of the steel casting plants in the United States amounting to 2,622,000 gross tons—an enormous amount, much larger than indicated by any previously published statistics.

A comparison of output with capacity is enlightening. The production of gross tons of steel castings in the United States in 1925 is reported by the American Iron and Steel Institute in its Special Statistical Bulletin No. 3, published June 12, 1926, to have been as follows:

Acid Open Hearth	462,303	
Basic Open Hearth	455,282	
Total Open Hearth		917,585
Electric		279,534
Converter		53,834
Crucible		1,833
Total		1,252,786

When the figures listed above are reduced to percentages they become especially significant. It is found that the proportion of output to capacity of each classified branch of the industry in 1925 was as follows:

Acid Open Hearth	49 per cent
Basic Open Hearth	50 per cent
Total Open Hearth	49 per cent
Electric	47 per cent
Converter	36 per cent
Crucible	49 per cent

It is further found that the capacity of each branch of the industry calculated with relation to the combined capacity is as follows:

Acid Open Hearth	36 per cent
Basic Open Hearth	35 per cent
Total Open Hearth	71 per cent
Electric	23 per cent
Converter	5.7 per cent
Crucible	.14 per cent

The percentages of the above correspond closely with those indicating the relative production in each of the three major

divisions of the industry, as reported for 1925. Open-hearth castings, which in 1910 represented 90 per cent of the entire output in the United States, last year amounted to 73 per cent. Electric castings in 1925 amounted to 22 per cent of the combined production of the industry, having doubled in percentage in 7 years. Converter castings in 1925 represented a trifle more than 4 per cent of the total output, having fallen more than 11 per cent in eight years.

We see finally that the industry we are discussing has a capacity of more than 2,600,000 gross tons per year, and that it produced in 1925 1,253,000 tons, or 48 per cent of capacity. We discover that the largest output of steel castings in the United States of which there is a satisfactory record, was 1,458,000 tons in 1923, when war time records were to slight extent exceeded. These statistics present the most conclusive proof of over-development, and should cause careful consideration by those who contemplate plant erection or addition. This means analysis of the extent to which each branch of the industry could supply its proportionate share of the total tonnage of steel castings used now and capable of being used economically in the future.

Unfortunately for some investors, steel foundries are not adaptable to other industrial purposes. Equipment for making steel castings, particularly those produced from metal made in open-hearth and electric furnaces, entails a large expenditure, and is difficult to remove to other localities. An electric or open-hearth steel casting plant maintains its industrial value only so long as it remains in its original location, and there supplies a fairly steady demand, which is generally a composite expression of the need for the product in a restricted territory. This may be comprehended if it is remembered that according to statistics reported by "The Foundry," in its issue for August 15, 1926, there are operating today, 357 steel foundries. Of these, 182 are said to be making electric steel.

Adaptation of Plant to Product

The war period and the following reconstruction days taught industry many useful things. The steel foundry operator

probably learned more in the five years ending in 1922 than he had ever learned before regarding the kinds of work that could be produced economically in his shop. His information along this line has been increased materially during the past four years by the careful assembly and broad distribution of data relating to costs. The problem of determining, at a reasonable expense and with desirable promptness, the actual cost of miscellaneous steel castings is one beyond the ability of the specialty shop operator to appreciate. The jobbing steel foundry has the disadvantage of a labor cost that is higher ordinarily than all other items of expense. Certain operations cover an enormously wide cost range. Prominent among these is the comprehensive treatment described generally as cleaning, in which the ratio between lowest and highest costs in a steel foundry making miscellaneous castings may be as one to twenty, without any corresponding difference in the production expense of any other department.

Without doubt, ignorance regarding classified and job costs is responsible for many serious handicaps imposed on themselves, by steel foundrymen in seeking work. Many who in recent years have studied carefully this phase of the business agree that the industry now is in a healthier condition than ever before, because of the growing realization by steel foundry owners that specific job costs present the only basis for the intelligent search for new business. Such costs are by no means easy to obtain. Ingeniously devised systems must be carefully tried out for an extended period before they can be regarded as satisfactory for prolonged universal application.

The analysis of job costs has resulted in important changes in manufacturing and merchandising policies in many plants. The conviction grows that the success of the industry as a whole will be dependent largely on the degree to which it becomes further specialized. This term is a rather difficult one for some to apply to jobbing shops. There, however, it is found that many factors other than weight limits can be established, making it feasible to eliminate work poorly suited to existing facilities, and to increase the volume of castings whose manufacture is well adapted to equipment and training locally characteristic.

Probably one of the most important developments in future specialization in the steel foundry industry, because of the amount of work affected, will be the exclusive manufacture in plants having melting units of small capacity, of castings well within the desirable weight limits for shops where special facilities are provided for small and medium-sized work; and the refusal of the larger open-hearth foundries to complicate their operations by the manufacture of castings under those weight and section limits that necessitate extra supervision at the expense of regular work, and temporary expedients because of the lack of special equipment.

Inevitably, as steel foundries are able to install satisfactory systems correctly allocating the many items collectively known as overhead expense, manufacturers of the product will find themselves specializing, sometimes perhaps without fully realizing it, through intensive merchandising efforts to secure work for which specially trained personnel and carefully selected equipment are available. Probably the exasperating complexity of steel casting manufacture has been magnified by the immaturity of the industry, and the resulting lack of specialized effort.

Eventually, all makers and users of the product will know how to classify the steel foundryman who claims to make satisfactorily for the discriminating consumer and profitably for himself, any kind of steel casting in a plant whose principle items of equipment for the major operations are not diversified and separately grouped.

Competitive Materials

The nature of competition that may be expected affords a topic for discussion in an attempt to gauge future conditions in the industry. The problem of competition has differing aspects for the several branches of the industry and for producers in each branch, according to the nature of the work being executed in individual plants.

Without attempting to make specific references to parts or devices now being produced in cast steel, forged steel, or malleable iron, some important principles underlying the economic

selection of each of these materials may advantageously be considered. The three metals just enumerated are referred to, because steel foundrymen generally will concede that their present and prospective efforts to maintain or extend the use of their product bear a closer relationship to the developed or expected adaptation of forged steel and malleable iron than to other materials.

The honest, farsighted, ultimately successful maker of any product does not commit the error of attempting to deceive the user regarding the ultimate economical application of the material submitted as one of several possible to employ. There is no justification for unscrupulous or unintelligent effort to exploit the use of cast steel, forged steel, or malleable iron for any specific application. Each of these materials has its preferred field, in which either of the other products eventually would be disadvantageously utilized, for one or more of several reasons.

No honest, well-informed steel foundryman will deny that properly made steel is slightly improved by skillful hot-working, if the design of the piece is such as to prevent strains from being set up in members to be subjected to service-stresses out of proportion to the resistance of the over-strained sections. No forging expert should deny that a steel object may be seriously injured by forging at improper temperatures or by peculiarities of design that cause excessive strain in locations not adaptable to the forging operation at temperatures within a working range that is suitable, practically and technically. Properly made steel forgings of certain designs are undoubtedly superior to steel castings, in some physical properties, assuming for the metal in each case equally skillful melting and pouring. It is appropriate to refer to the fact that necessarily, steel for castings generally is delivered from the furnace in a more thoroughly degasified condition than is steel poured in ingots to be subsequently forged; and through that operation to have any gas cavities flattened and apparently eliminated, often not visibly affecting the soundness of the forged article, but actually establishing a potential cause for failure.

These comments are made with no desire to criticise the qualities of the average steel forging, or to deny the economic

employment of forgings as compared with castings for certain purposes. The number of pieces required from a single design and the comparative costs of pattern and die equipment are factors of prime importance in choosing the product of the foundry or forging shop, in most cases. But there are other considerations such as have been suggested above which should be kept in mind by the user. He who employs either a casting or a forging should not delude himself by the impression that the properties ascertained from a tensile test piece are necessarily indicative of those in each member of any finished steel part, especially one of complicated design.

Fortunately, in the competition between steel foundrymen and malleable iron foundrymen, unjustified claims regarding average properties of either product are being eliminated. There ought to be and doubtless will be in the near future, a mutually appreciative and fairly competitive spirit actuating both classes of producer. Probably this condition will depend on recognition on the part of manufacturers of the weaker material, of the properties of the stronger one; and admission on the part of the makers of the stronger material, that it is economical to employ the weaker one where the severity of known service conditions does not overtax the resistance of the product, and where consequently the weaker material, being cheaper, should be selected. The terms strength and weakness are here employed in a general sense, embracing toughness.

Comparisons are odious in metallurgy only when they are unfair in origin, interpretation, or acceptance. The final success of any manufacturing establishment will depend in no small degree on its honesty in promulgating information regarding its own product, and in meeting claims made for rival products. Neither of the two industries that can be reasonably considered as occasional competitors of the steel foundry industry can be attacked advantageously by efforts to sell steel castings where forgings or malleable castings should be employed. The forger and the malleable founder will not gain lasting benefits from efforts to introduce their products where, from an economic standpoint, steel castings should be applied.

Looking forward and judging from developments of the last decade as well as from reasonable prospects, it would appear that the steel foundryman has every reason to be optimistic regarding the competition of the future, in so far as it may relatively affect his merchandising efforts to maintain and to further advance the extensive use of steel castings.

Specifications for Steel Castings

Considerable could be written about past, present, and future developments relating to specifications for steel castings. Mention has been made of the requirements customarily prescribed in the beginning of the present century when ductility values far below those demanded today were acceptable to ordinary consumers of steel castings. There was a very wholesome effect on the industry produced by the zealous systematic study of the behavior of steel castings under shocks and stresses of exacting kinds, undertaken about 1900. Such analysis of performance was stimulated greatly by war needs embracing in many cases conservation of weight and maximum toughness or resistance to wear under heavy demands. Discovery of the highly important relationship of heat-treatment to the above mentioned and other characteristics of performance had much to do with the stimulation of steel foundrymen in improving methods for annealing, normalizing, and heat-treating according to special procedures, the products of their plants.

Almost simultaneously with the development of information on the influence of heat on the physical properties of steel came the beginning of systematic investigations of alloy steels for castings, for a fairly wide variety of uses. Probably the handicap to the steel casting industry of over-expansion during a few years, was more than offset by the stimulated development of scientific heat-treatments and the origination of those combinations of the elements which place the product in the category termed alloy steels.

Unfortunately, some years ago there developed the tendency of certain consumers to include chemical limits other than those for phosphorus and sulphur, while prescribing minimum physical properties. It is regrettable that this movement gained followers

to an extent that has handicapped steel foundrymen who have been placed under unreasonable restrictions occasionally by lack of technical knowledge displayed by some consuming interests. Certain individuals advocate rejection limits for carbon, manganese, or silicon, one or more, in a product required to have minimum values for physical properties, but which would not be influenced harmfully by wide deviations from chemical limits proposed. Engineers preparing specifications should not lose sight of the fact, of enormous significance in metallurgy, that the percentage of any element cannot be scientifically considered except with relation to the prevailing percentages of many, if not all of the other elements in the steel. This renders ineffective the helpful purpose undoubtedly actuating those who, for example, would, if they could, limit the steel casting producer to a maximum manganese content of .85 per cent. The proper proportion of manganese or silicon, or each of certain other elements, is what is needed according to the existing combination of the elements in the metal, considered with respect to the anticipated service of the product.

Imposing comprehensive chemical limitations causes the purchaser to assume a portion of the responsibility that should be placed alone on the manufacturer. An additional handicap is the discouraging effect on steel makers, some of whom would probably have shown more zeal than they have exhibited in the intentional production of steel of unusual chemical composition for experimental purposes, if there had not been manifested by certain consumers a conviction that they should reject metal containing percentages of the elements differing from those narrowly prescribed.

An instance of misguided effort made by some responsible consumers to prescribe how steel shall be made, may be mentioned. The writer was confronted a few years ago by a specification dated March 28, 1917, prepared by the engineers of a well known company making boiler plant equipment. The specification was for important steel valve castings. The blue print showing the castings called for acid open-hearth steel, annealed, to have a silicon content of from 2.00 to 2.50 per cent; a sulphur content of .08 per cent; a phosphorus content of .40 per cent;

a manganese content of .60 per cent; and a carbon content of 3.25 per cent. Physical tests were required for the material specified. It is unnecessary to elaborate on the negotiations that resulted in the delivery of a suitable product. It bore no resemblance chemically to the material specified by the engineers.

Fortunately, for the benefit of the producers and consumers of high grade steel castings, it is gradually becoming apparent to those clothed with the responsibility of preparing specifications for steel castings, that ambiguous language should be excluded; that recommendations as to foundry practice have no proper place in instruments like specifications, the clauses of which should be of mandatory character; that indefinite conditions regarding heat-treatment should be succeeded by positively worded provisions instead of such phrases as: "The castings shall be properly annealed;" that there are a great many details of foundry practice not mentioned even by suggestion in many commercial specifications which are of the greatest importance in the production of sound steel castings, some of which deserve consideration as reasonable to cover in a positive manner, affording desirable protection to the buyer and appropriate latitude to the seller; that it is, in brief, equitable and scientific to use specifications for steel castings which place no undivided responsibility for careful manufacture on the foundryman through the imposing of unwarranted chemical limitations, but which will prescribe so far as is practicable, those details conceded to be safeguards in making a product, the characteristics of which cannot be completely gauged by the customary physical tests, by chemical analysis, by microscopic examination, or by all of these means combined. The writer believes that during the next decade there will develop a significant movement in the direction indicated, which will result to the distinct advantage of high grade producers and those whom they supply.

A few comments seem advisable regarding limitations for sulphur and phosphorus. The Joint Committee on the Investigation of the Effects of Phosphorus and Sulphur in Steel has been conducting a comprehensive research into the effect of sulphur for approximately seven years, and has published, through the agency of the American Society for Testing Materials, several

preliminary reports. The last of these, presented at the June, 1926, Convention of the Testing Society, was the first expression of a conclusion reached by the joint committee. In the past, engineers have not agreed as to the desirable upper limit. The more liberally minded have established the dead line at .06 per cent, while the ultra-conservative contingent has looked askance at a sulphur content exceeding .04 per cent. It is not surprising that previously, in the absence of authoritative information as the result of a sufficient number of comparable tests, judicious engineers have followed the policy of playing safe. The published results of thousands of tests covering the extraordinary comprehensive investigation by a large representative committee which conducted its research by disregarding all theories previously held, afford a scientific basis for universal agreement that a sulphur content of .06 per cent does not reduce the serviceability of steel castings.

The technical world will now look forward with great interest to the periodic publication of data by the joint committee on the effects of phosphorus. The study of this element is to be undertaken soon. It would be premature now to offer any comments regarding desirable modifications of the required phosphorus content in specifications for steel castings. There should be an open mind on this subject until the facts are ascertained.

Future Technical Investigations

It would be presumptuous of anyone to make definite prophesies covering numerous specific fields of research which will be attacked most successfully by the industry in the future. There are many operations that have been under investigation, which have yielded a great deal of value and will continue to place at the steel founder's disposal, data on which to base improved practices. Some subjects have been studied in a haphazard manner, occasionally by individuals who were at a disadvantage because they had routine operating responsibilities. It may not be out of place here to refer to a few investigations of present and future significance.

A subject to which considerable study has been effectively given during the last five years is that of molding sand, regarding

which it is unnecessary to elaborate here. The work of the Joint Committee on Molding Sand Research should be well known to all foundrymen. It should be unnecessary to advocate hearty support of the work of the joint committee, which centers the attack on the problem by means of organized co-operation, the results of which are available to the technical world. Many steel foundrymen have obtained and more will secure in the future, distinct advantages from the activities of this joint committee.

In the search for an ideal facing sand, possibly all steel foundrymen at some time have committed the error of observing the apparent results of the facing without proper regard for the contaminating influences on the castings, of unclean and improper gating, and unskillful pouring. Many steel foundrymen have reached the conclusion that there are numerous grades of sands that are probably well suited to their product, if they are skillfully bonded and handled. Probably the average steel foundry of the future will devote much more attention than it does now to the careful proportioning of the ingredients, to their thorough blending, to the regulated percentage of moisture, and to the suitable handling and storage of the prepared sand in ways that will prevent deterioration and subsequent unskillful treatment by the molder. Means will probably be provided in many steel foundries for daily gauging refractory properties to prevent deterioration of the heap sand. Sand control methods have made their entry into progressive steel foundries in a manner that assures the permanency and future expansion of the policy.

The degasification of steel, which is a more correct term than deoxidation, frequently employed as indicative of the identical condition, presents a problem of baffling nature even to those steel foundrymen who have personnel and equipment for conducting intensive studies embracing practical and theoretical details, both necessary for the proper consideration of this subject. Reference has been made in the earlier portion of this paper to the importance for the industry of the development of green sand molding, within our memory. A feature of this kind of molding, relating in an important way to the reasonably thorough degasification of steel, is the influence on it of the high percentage of

moisture in green sand as compared with the proportion in an oven-dried mold.

There are highly qualified metallurgists associated with companies skillfully producing certain alloys, the chief function of which is to cleanse the steel by the liberation of gases. Unfortunately some of these gentlemen, through lack of familiarity with commercial steel foundry conditions, make deductions and give assurances regarding the useful substitution for aluminum, of alloys that prove to be disappointing in the two-fold effort to maintain in the metal the original degree of ductility, and to put the steel in such a condition when poured in a green sand mold containing ordinarily from 4 per cent to 5 per cent moisture, that there will not exist in the interior or on the surface of the resulting castings, the slightest evidence of porosity, commonly termed "pin-holes." Pouring steel into molds containing a fair percentage of moisture, and pouring it into cast iron ingot molds are two very different things, particularly when we keep in mind the mechanical processes to which the ingot is later subjected, changing in a radical manner the characteristics of the pockets originally containing gas.

Without doubt there is opportunity for the prolongation of carefully planned investigations to develop a material that will serve the double purpose to which we have referred. It may be that the complete elimination of aluminum in the steel foundry is an objective that will never be reached. A few writers on steel foundry topics have occasionally referred to shop practices in a way indicating that they do not employ this element because of its bad influence on physical properties. Technical exploiters of deoxidizers have expressed themselves along similar lines. Painstaking efforts to obtain evidence from the manufacturers of deoxidizers and degasifiers discloses nothing completely satisfactory, when the standard employed for determining the results is a green sand mold of a design that, despite liberal provision for mechanical venting, has, by experience, been found somewhat peculiarly susceptible occasionally to a few pin-holes. Practical steel foundrymen know that such susceptible casting designs exist, and that successful manufacture in such cases is attended by intelligently regulated aluminum additions.

In the final analysis, the interests of steel foundrymen, of their very helpful associates who produce degasifying alloys, and of consumers who need steel castings of the highest grade, will not be served by attempts to cloud the issue that presents for the future, a problem justifying a great deal of research. Among other things, the progressive steel foundryman has learned that it pays to be frank, and that exaggerated claims and deceptive gestures are not profitable eventually.

Much has been done within the last 10 years to ascertain the potential physical properties in steel castings by the application of varied forms of heat-treatment. There has been considerable impetus given our own industry in this respect through the concentration of attention on the subject by users of an enormous variety of steel products other than those made in the foundry. The rapid growth of the American Society for Steel Treating is sufficient evidence of the present aggressive disposition to develop heat treatments best suited to the peculiarities of the product. Researches in the steel foundry for many years will be conducted into the subject of heat-treatment, and will, of course, include consideration of the different types of ovens, including those lately developed which employ electric current. Some of these obviously permit a more thorough distribution of heat than can be arranged for in a fuel fired furnace.

Among the operations that have provided channels for investigation are those related to gating and heading. There is no necessity for elaborating on this topic, but it can be appropriately mentioned as one deserving the continuous attention of investigators, many of whom will learn more than they now know regarding the principles that ought to be observed in permitting entry of the metal, and ample but not excessive opportunity to supply the voids created during solidification. This problem is one of particularly local significance. It is made complex in the jobbing shop, where broad experience and marked ingenuity can be regarded as indispensable for economical practice, frequently aided by experimental work.

The composition control of steel is a factor in the satisfactory nature of the foundry's product which is deserving of research in many plants. The close approach to the locally desired propor-

tion of each of the five commonly determined elements in steel, even when followed by properly applied heat-treatment, by no means provides invariably the means for obtaining superior physical properties. The steel may be very inferior, yet come within close chemical limits prescribed. The result of the annealing or normalizing treatment may be all that could be expected, yet the performance of the physical test specimens may show undesirable material. However, the satisfactory uniformity and agreement with established values of physical tests cannot be expected unless there is a very fair degree of uniformity in chemical composition. For this reason and because of the fact that never can steel melting be positively and completely controlled, there is opportunity for useful research in the future, to closely approach the ideal of undeviating chemical composition.

There are almost innumerable opportunities for future research in the steel foundry. Many investigations can be prosecuted into operations that are quite dissimilar and have important cumulative effects on the product. Certain investigations naturally divide themselves somewhat along what are considered the more scientific lines that are primarily theoretical, and those regarded as of more practical significance. When analyzed closely, many of these two ordinarily made distinctions disappear. Research must be practical to justify itself in industry. The true measure of practicability is the probability of applying the information obtained, with ultimate economic advantage. Disregarding the element of time, we might consider that there are so many opportunities for investigations that may result usefully, that our distinctive use of terms is superfluous, and brings us back to the same starting point for classification. The logical method for making progress that will be recognized and encouraged by those who make steel foundry research possible, is the practical attack aided by theoretical study, of problems according to the preferential order of their present seriousness, considered with respect to early future needs.

We have perhaps suggested the elimination of narrowly defined practical and theoretical classifications for steel foundry investigations. It is not out of place to indicate the maintenance of a practical viewpoint as an indispensable feature of steel foun-

dry research. Any one clothed with the responsibilities of conducting technical investigations in our industry should know steel castings; and should understand, to considerable extent, the conditions that daily attend foundry operations, where there is nothing that bears a resemblance to the quiet atmosphere or the fine precision characterizing the laboratory, exerting an important influence on personnel.

The writer has in this final section dwelt at considerable length on a few of the possibilities for future researches in the steel foundry. He does not wish thus to pose as being original. Occasionally, topics acquire their true significance only by fairly frequent reference serving to emphasize them. There should be no doubt that technically and commercially the future of the steel foundry industry in the United States will be directly and closely related to the investigations that will be made into the details of manufacture, distribution, and performance of the product. When the middle of the present century is reached, marking achievements in the manufacture of steel castings in the United States for 85 years, the conditions of the industry will present a reflection of the investigational work done by it within the next 20 years.

Manganese in Cast Steels

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For many years, manganese as an alloying element in cast steel has been known chiefly from the extensive use of the 12 per cent alloy discovered by the Hadfields in the early 1880's, which has found a wide field of usefulness as a wear-resisting steel. The original discoverers, however, reported that manganese in amounts below about 7 per cent made steel exceedingly brittle, and these findings, coupled with the experience of the early makers of Bessemer rail steel, caused a ban to be placed on steels containing from a little over 1 per cent to 9 per cent or 10 per cent manganese, the lower limit of the useful range of wear-resisting steels. As a result, the adoption of moderate amounts of manganese as an alloy addition to steel was for many years hardly even considered, and has only lately been taken up actively.

Summary Previous Investigations Data

In 1906, M. Leon Guillet, the eminent French metallurgist, published his "Industrial Study of Metallic Alloys," including the results of a systematic study of the alloys of iron, carbon, and manganese. These results are diagrammatically summarized in Fig. 1, the well known diagram of the constitution of the iron-manganese alloys, reproduced herewith. M. Guillet was one of the first to call attention to the possibilities of moderate amounts of manganese as alloying additions in steel.

According to this diagram, all steels above the line connecting the points 14 per cent manganese and 1.65 per cent carbon consist of austenite. M. Guillet did not take account of the presence of cementite in the austenitic steels containing over 1 per cent carbon, and the lines X Y and W Z have been added to the diagram as the result of a research made in 1906 by H. M. Howe, William Campbell, and the author. Steels whose composition lies between these lines consist of pure austenite when

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quenched from temperatures above about 1,000 degrees C. With carbon above the line W Z, whose equation is,

$$C = 1.075 + \frac{0.1\ Mn}{3},$$

free cementite will be found in the steels even after quenching. With carbon below the line X Y, whose equation is, C = 1.075 — 0.04 Mn., the steels contain both austenite and martensite after quenching. Thus the limits of the range of composition of useful austenitic manganese steel are narrower than Guillet's diagram would lead one to expect.

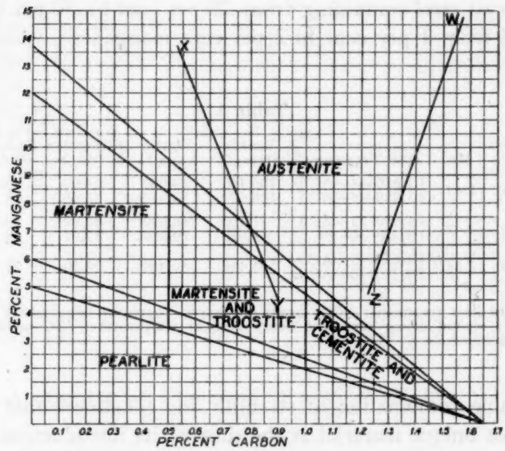

FIG. 1—SUMMARIZATION OF CONSTITUTION OF IRON-MANGANESE ALLOYS (GUILLET DIAGRAM MODIFIED)

The martensitic manganese steels have not yet found any industrial use, as far as the author is aware, on account of their great brittleness; but in the portion of Guillet's diagram marked "Pearlite," lies a range of possible compositions of great promise, in which active exploration is being carried on by a number of investigators.

Steels containing from .30 per cent to .50 per cent carbon and from 2 per cent to 3 per cent manganese, lying as they do close to the martensitic range, are pearlitic and comparatively

tough in the annealed condition, but can be rendered martensitic and exceedingly hard by a simple air cooling from about 900 degrees Cent., and should, therefore, be useful for the manufacture of parts difficult to harden in water without cracking. The following physical properties have been obtained from cast steels in this range of composition, as shown in Table 1.

The most widely used of the lower manganese steels, however, contain from 1 per cent to 2 per cent manganese, and carbon from about .20 per cent to about .50 per cent. The company with which the author is connected pioneered the investigation of cast steels of this composition, and in 1909 developed a heat treated cast steel containing from .20 per cent to .30 per cent carbon and from 1 per cent to 2 per cent manganese, which had a

Table 1

C.	Si.	Mn.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 Inches	Per Cent Reduction of Area	Bend
0.36	0.24	2.42	1,650—4—AC	106,450	54,080	14.03	19.45	45
			1,250—6—AC	106,600	52,990	13.68	18.30	50
0.36	0.24	2.42	1,650—3—AC	97,700	68,800	12.00	20.10	75
			1,220—6—SC	97,950	70,200	17.07	28.09	70
0.32	0.19	2.38	1,650—3—AC 1,250—6—AC	103,400	59,390	18.20	29.20	..

*Key to heat treatment: First group of figures represent temperature in degrees Fahrenheit; second group represent hours held at temperature. SC—slowly cooled; AC—cooled in air.

remarkable combination of strength and toughness that made it an almost unique material at the time of its introduction. It has since been produced under a variety of trade names, in addition to its original name of *orbit* steel, and is being used to an increasing extent for service requiring castings of great strength coupled with toughness.

The author has published data on the physical properties of this steel on numerous occasions, and feels that to extend the record here would be a superfluous task. During the past year, however, research upon the elastic properties, shock toughness and endurance strength of this steel has been carried on in our laboratories, and it was thought that the results of these investigations to date would prove of interest at this time.

Stress-Strain Diagrams of Orbit Steel

In Fig. 2 are shown the stress-strain diagrams of eight specimens cut from coupons of heat treated orbit steel, tested with an Olsen extensometer reading to 0.00006667 of an inch, the first six bars being tested in a gauge length of 8 inches and the other two in 2 inches. The latter are plotted to such a scale as to be comparable with the other six specimens. It will readily be seen that the curves approximate closely to a straight line, so that the limit of proportionality is well marked, and the modulus of elasticity

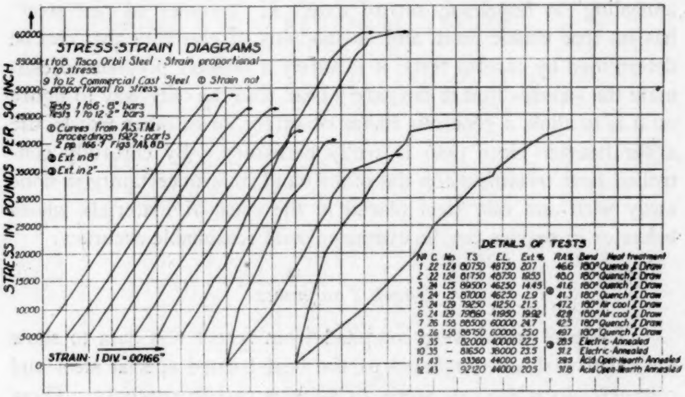

FIG. 2—STRESS-STRAIN DIAGRAMS OF SPECIAL STEELS AND COMMERCIAL CAST STEELS

can be figured with considerable accuracy from the test data. Had more than one extensometer been attached, the curves would no doubt have been smoother.

Curves 9 to 12 are taken from an article by L. H. Fry[1], the curves being redrawn to correspond with the scale on which the data on orbit steel are plotted. The irregularity of the latter curves, which represent commercial cast steel, is at once apparent, and the impossibility of figuring a modulus of elasticity from these curves is evident. In his discussion of his

[1] L. H. Fry, "*Tensile Properties of Steel Castings,*" Proc. A. S. T. M., Vol. 22 (1922), p. 150.

results, Mr. Fry states, "The curves plotted from the whole body of tests lead to the belief that a tension specimen of cast steel stretches irregularly under a gradually increased load. This irregularity ****** is largely due to the nature of the material, ******. Precise measurement and plotting of the stress-strain curve fails to determine a 'true elastic limit' for cast steel." A study of Mr. Fry's results, and of the properties of heat treated cast steel such as is shown in curves 1 to 8 (Fig. 2), has served only to deepen the author's conviction that for all service where it is desirable to have a material capable of resisting repeated heavy stresses, heat treatment of cast steel is absolutely essential, and "old fashioned annealing" is hopelessly out of date. If "commercial cast steel" has no true elastic limit, and no modulus of elasticity that can be determined by careful tests, it is surely a difficult problem to estimate the stresses that it can safely bear, and the only way to figure on it is to allow a generous factor of safety, or in other words, use a far heavier piece than is really necessary. By carefully controlled heat treatment, on the other hand, this uncertainty is done away with and cast steel placed in the class of materials whose behavior in service can be estimated with reasonable accuracy.

Shock Toughness

Tables 2 and 3 were compiled from recent test data to show the relative shock toughness of the heat treated special steel and commercial carbon cast steels of various carbon contents. These tests were made on specimens cut from cast coupons, in a Charpy machine made by Tinius Olsen of Philadelphia, of 30 kgm capacity. In all but one case, the average of two readings is given.

Table 2 shows clearly the relatively low resistance to impact of ordinary cast steels with a plain anneal, and the somewhat higher shock toughness that can be obtained by special heat treatment. It is also apparent from an inspection of Table 3, and certain of the figures in Table 4, that the high manganese steel, which has been given a plain annealing, offers a relatively low resistance to impact. This fact is further shown by a comparison of the companion tests of heats 3676, 3663, 3685, 3680, 3688, and 3662, made on pairs of coupon, one of which received a plain annealing, the other a heat treatment. In every case, the extension, reduction of

Table 2

CARBON STEELS

Test No.	Heat	C.	Si.	Mn.	S.	P.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 Inches	Per Cent Reduction of Area	Bend	Charpy Kgm.	Charpy Ft. Lbs.
4014	C4014	0.14	0.22	0.64	0.047	0.045	1,650—4—SC	60,250	33,500	37.0	59.4	180	2.498	18.06
2441	C4344	0.18	...	0.73	0.067	....	1,650—4—SC	67,000	38,250	31.0	49.2	180	1.580	11.42
2440	C4333	0.21	0.31	0.67	0.071	0.046	1,650—4—SC	68,500	41,250	32.5	48.6	180	1.580	11.42
2044	C3940	0.20	0.29	0.73	0.045	0.044	1,650—4—AC 1,250—6—AC	69,000	41,500	34.5	58.6	180	2.809	20.30
3726	C3726	0.20	0.25	0.79	0.052	0.052	1,650—4—AC 1,250—6—AC	67,500	38,000	35.0	60.6	...	2.991	21.62
3940	C3940	0.20	0.29	0.73	0.045	0.044	1,650—4—AC 1,250—6—AC	69,000	41,500	34.5	58.6	180	2.565	18.56
605	E2213	0.24	0.24	0.67	0.058	0.048	1,550—4—SC	64,750	40,500	22.5	25.2	70	1.016	7.34
604	E2212	0.26	0.21	0.63	0.046	0.043	1,550—4—SC	73,000	42,000	26.0	34.7	110	1.362	9.86
2438	C4285	0.27	...	0.75	0.072	....	1,650—4—SC	74,250	43,500	13.5	14.8	40	0.758	5.48
3777	C3777	0.28	0.30	0.73	0.054	0.039	1,650—4—SC	76,000	39,000	27.0	41.3	175	1.220	8.83
602	E2203	0.30	0.26	0.83	0.052	0.045	1,650—4—SC	75,750	48,250	20.0	21.7	70	1.083	7.84
4103	C4103	0.32	0.39	0.78	0.049	0.046	1,650—4—SC	77,500	45,000	17.0	19.5	50	0.949	6.85
3901	C3901	0.32	0.34	0.73	0.048	0.041	1,650—4—SC	79,500	43,750	20.0	20.6	...	0.885	6.40
1661	E2522	0.33	0.21	0.88	0.054	0.040	1,650—4—SC	78,500	41,000	22.0	28.2	50	0.949	6.85
2324	C4103	0.32	0.39	0.78	0.049	0.046	1,550—4—AC 1,250—6—AC	71,000	47,500	16.0	16.7	50	0.949	6.85
2571	E2571	0.37	0.24	0.87	0.038	0.038	1,650—4—SC	81,500	44,250	18.0	25.2	60	1.155	8.00
2389	E2610	0.40	0.25	0.54	0.052	0.041	1,650—4—SC	79,000	38,250	20.0	24.4	65	0.8206	5.43
1693	E2528	0.42	0.19	0.79	0.056	0.035	1,650—4—SC	81,250	42,250	15.5	19.9	45	0.889	6.42
2387	E2606	0.43	0.21	0.85	0.044	0.039	1,650—4—SC	82,500	41,000	16.5	19.5	60	0.4576	3.31
2263	E2595	0.43	0.26	0.90	0.041	0.036	1,650—4—SC	90,000	44,500	22.0	36.0	93	1.220	8.82
2388	E2608	0.45	0.21	0.84	0.042	0.040	1,650—4—AC 1,250—6—AC	83,500	48,500	11.0	11.1	130	1.291	9.35
2328	E2604	0.47	0.27	0.88	0.050	0.044	1,550—4—AC 1,250—6—AC	81,000	49,500	29.0	48.3	180	1.505	10.88
2569	E2569	0.57	0.35	0.99	0.045	0.037	1,650—4—SC	110,000	65,750	10.0	11.5	45	0.6391	4.62

*Key to heat treatment symbol: First group of figures indicates temperature in degrees Fahrenheit; second group of figures indicates hours held at temperature. SC—slowly cooled; AC—cooled in air; Q—quenched in water.

Table 3

HIGH MANGANESE STEEL

Test No.	Heat	C.	Si.	Mn.	S.	P.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 Inches	Per Cent Reduction of Area	Bend	Charpy Kgm.	Charpy Ft. Lbs.
....	C3676	0.23	0.25	1.02	0.086	0.049	1,650—4—SC	74,750	40,000	24.5	36.9	140	0.949	6.86
....	C3663	0.25	0.30	1.22	0.081	0.048	1,650—4—SC	78,000	42,000	25.0	36.9	80	0.346	2.50
....	C3685	0.22	0.28	1.24	0.089	0.046	1,650—4—SC	78,500	40,750	27.2	41.6	135	0.5162	3.73
....	C3680	0.25	0.26	1.29	0.079	0.045	1,650—4—SC	75,750	40,000	26.2	38.8	140	0.6477	4.68
....	C3688	0.26	0.31	1.35	0.079	0.048	1,650—4—SC	80,500	42,500	24.0	36.9	145	0.5456	3.95
....	C3662	0.21	0.27	1.36	0.080	0.052	1,650—4—SC	78,250	42,750	27.0	41.9	85	0.4576	3.31
2515	C4534	0.27	0.45	1.58	0.066	0.056	1,650—4—SC	90,500	51,000	25.0	42.5	180	0.5205	3.76
4097	C4097	0.27	0.32	1.66	0.071	0.044	1,650—4—SC	.....	.....	...	...	...	0.2391	1.73
....	C3676	0.23	0.25	1.02	0.086	0.049	1,650—4—AC 1,250—6—AC	69,250	39,250	29.5	47.5	180	....	....
....	C3663	0.25	0.30	1.22	0.081	0.048	1,650—4—AC 1,250—6—AC	75,750	42,000	31.0	49.2	180	....	....
....	C3685	0.22	0.28	1.24	0.089	0.046	1,650—4—AC 1,250—6—AC	73,000	42,000	30.0	47.8	180	....	....
....	C3680	0.25	0.26	1.29	0.079	0.045	1,650—4—AC 1,250—6—AC	70,750	38,000	30.0	47.2	180	....	....
2439	C4327	0.27	0.25	1.30	0.076	0.051	1,650—4—AC 1,250—6—AC	80,250	45,250	27.0	41.0	175	1.151	8.32
1641	C3636	0.29	0.38	1.31	0.079	0.047	1,650—4—AC 1,250—6—AC	75,750	50,000	29.0	49.7	180	1.580	11.42
....	C3688	0.26	0.31	1.35	0.079	0.048	1,650—4—AC 1,250—6—AC	75,000	40,750	30.0	49.2	180	....	....
....	C3662	0.21	0.27	1.36	0.080	0.052	1,650—4—AC 1,250—6—AC	74,250	41,000	30.0	45.4	180	....	....
3881	C3881	0.26	0.31	1.36	0.076	0.045	1,650—4—AC 1,250—6—AC	80,750	41,500	28.5	45.7	180	1.580	11.42

*Key to heat treatment symbols: First group of figures indicates temperature in degrees Fahrenheit; second group of figures indicates hours held at temperature. SC—slowly cooled; AC—cooled in air; Q—quenched in water.

(Concluded on next page)

Table 3

HIGH MANGANESE STEEL *(Concluded)*

Test No.	Heat	C.	Si.	Mn.	S.	P.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 Inches	Per Cent Reduction of Area	Bend	Charpy Kgm.	Charpy Ft. Lbs.
2042	C3902	0.26	0.32	1.48	0.072	0.044	1,650—4—AC 1,250—6—AC	86,250	47,500	27.5	47.8	180	1.505	10.88
2484	C4379	0.30	0.27	1.62	0.078	0.047	1,650—4—AC 1,250—6—AC	91,000	48,500	25.5	44.9	180	1.658	11.98
4097	C4097	0.27	0.32	1.66	0.071	0.044	1,650—4—AC 1,250—6—AC	.....	.....	...	...	...	1.966	14.20
....	C94154	0.24	0.32	1.14	....	....	1,650—4—Q 1,200—6—AC	86,750	56,750	26.4	61.8	180	2.300	16.65
....	C95050	0.31	0.31	1.47	....	....	1,650—4—Q 1,200—6—AC	85,000	51,750	24.3	55.7	180	3.360	24.30
....	C94215	0.25	0.40	1.50	....	....	1,650—4—Q 1,200—6—AC	87,700	64,150	27.0	59.2	180	2.995	21.60
....	C94142	0.31	0.46	1.53	....	....	1,650—4—Q 1,200—6—AC	97,500	74,250	20.7	37.9	80	1.811	13.07
2493	C 4438	0.30	0.33	1.53	0.078	0.046	1,650—4—Q 1,200—6—AC	92,000	57,250	27.5	46.3	180	2.564	18.53
....	C94186	0.27	0.39	1.63	....	....	1,650—4—Q 1,200—6—AC	98,250	77,500	22.3	48.3	180	2.292	16.60
....	C95038	0.33	0.49	1.80	....	....	1,650—4—Q 1,200—6—AC	119,700	84,885	17.4	26.3	70	2.345	16.98
....	C94298	0.30	0.54	1.81	....	....	1,650—4—Q 1,200—6—AC	95,800	75,000	22.2	43.8	70	2.498	20.35

*Key to heat treatment symbols: First group of figures indicates temperature in degrees Fahrenheit; second group of figures indicates hours held at temperature. SC—slowly cooled; AC—cooled in air; Q—quenched in water.

Table 4

HIGH MANGANESE AND VANADIUM CAST STEEL COMPARED

Heat	C.	Mn.	Va.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 inches	Per Cent Reduction of Area	Bend	Charpy Kgm.	Charpy Ft. Lbs.
C3702	0.32	0.90	....	1650—4—Q 1200—6—AC	89,250 86,500	58,750 52,500	18.9 22.1	24.8 28.5	70 65	1.505	10.88
C3702 V	0.34	0.85	0.25	1650—4—Q 1200—6—AC	90,750 89,000	67,500 70,000	16.95 18.0	28.2 25.5	65 60	1.505	10.88
C3702	0.32	0.90	....	1650—4—SC 1650—4—SC	79,500 79,750	41,750 42,000	23.25 22.25	31.5 26.2	70 65	0.6391	4.63
C3702 V	0.34	0.85	0.25	1650—4—SC 1650—4—SC	89,750 89,750	55,750 53,750	16.5 16.9	19.9 19.9	42 45	0.8206	5.43
C3701	0.27	1.35	....	1650—4—Q 1200—6—AC	95,250 95,500	59,000 60,000	28.0 28.0	46.3 47.8	160 95	2.631	19.05
C3701 V	0.28	1.36	0.18	1650—4—Q 1200—6—AC	103,000 100,250	75,500 76,750	22.25 12.0	42.2 24.4‡	80 85	2.720	19.8
C3701	0.27	1.35	....	1650—4—SC 1650—4—SC	82,000 81,750	44,500 44,250	25.35 24.5	38.8 39.1	170 145	0.345	2.50
C3701 V	0.28	1.36	0.18	1650—4—SC 1650—4—SC	92,750 92,580	57,750 58,365	20.45 20.5	33.5 29.3	85 85	0.8206	5.43
C3743	0.30	1.47†	....	1650—4—Q 1100—6—AC	101,750 102,250	81,250 82,750	19.9 19.6	51.7 52.2	170 140	.....	....

*Key to heat treatment symbols: First group of figures indicates temperature in degrees Fahrenheit; second group of figures gives hours held at temperature. SC—slowly cooled; AC—cooled in air; Q—quenched in water.

†Si. 0.29 per cent; S. 0.05 per cent; P. 0.051 per cent.

‡Flawed bar.

area, and angle of bend of the heat treated specimens is considerably higher than that of those given a plain anneal. It is unfortunate that Charpy figures for the heat treated specimens are not available.

When heat treated by "normalizing and drawing back," the high manganese steel gives a comparatively high shock test, higher on the average than that of any of the ordinary cast steels shown in Table 2 except the very low carbon steels. After "quenching and drawing back," the high manganese steel averages higher in shock resisting value than any of the ordinary cast steels, including the dead soft material with carbon from .14 per cent to .20 per cent. It is of interest to compare the average *yield point* of the heat treated special steel with the average *tensile strength* of the .14 per cent to .20 per cent carbon material, in view of the fact that both steels give about the same Charpy impact value. The comparison is as follows:

.14 to .20 Per Cent Carbon Steel		Heat Treated Special Steel	
Average Tensile Strength	Average Charpy Foot Pounds	Average Elastic Limit	Average Charpy Foot Pounds
66,840	16.89	67,690	18.51

It is evident from this comparison that the high tensile strength and elastic limit of the special steel are not obtained at the expense of ductility and shock resisting qualities, as would be the case were the high strength secured by increasing the carbon, but are accompanied by an increase of toughness in both static and dynamic tests.

Relative Effect of High Manganese and Vanadium

The tests in Table 4 were made on two heats of steel, one of .32 per cent carbon and one of orbit, to ascertain the relative effect of high manganese and of vanadium in cast steels. From each heat about 500 pounds of metal was poured into a bull ladle, the proper amount of ferro-vanadium being thrown in while the bull ladle was being filled. A second bull ladle was then filled with metal to which no vanadium was added, and coupons were poured from the two ladles at as nearly as possible the same temperature. The bars cut from the coupons were treated side by side in an electrically heated laboratory muffle furnace, care being taken that the steel with and without vanadium was subjected to exactly the

same conditions. All variables except the vanadium were thus eliminated as far as possible. Two bars from each coupon were tested.

An inspection of the table shows that in every case the vanadium raised the yield point and the tensile strength of the steel to a considerable extent. The extension, reduction of area, and bend were decreased by the vanadium in almost every case, though the Charpy impact value is, if anything, slightly raised by the vanadium addition. The high manganese steel with a plain annealing, however, gives a better tensile test and bend than the carbon-vanadium steel in the same condition, though a lower Charpy value, and when "quenched and drawn back," the high manganese steel gives nearly four times the shock toughness of the carbon-vanadium steel plain annealed, with better tensile figures and bends. Even when "quenched and drawn back," the carbon-vanadium steel gives but half the shock toughness of the high manganese steel in the same condition, and not as high extension, reduction of area and bend. It is also worth noting that the Charpy value for the carbon-vanadium steel with a plain anneal is not as high as that of the plain carbon steels of equivalent carbon shown in Table 2. The last test in Table 4 was made on a coupon from another heat of the special steel, heat treated to give a very high elastic limit. No Charpy test was made on this coupon, but the results in the last two lines of Table 3 indicate that this high elastic limit can be obtained with but little sacrifice of impact strength.

It would appear from these figures that the increase of elastic limit and tensile strength due to vanadium is accompanied by a considerable decrease in the toughness of the steel, whereas the increased strength obtained by additions of manganese coupled with suitable heat treatment is accompanied by a great gain in ductility and shock strength. In considering these figures, it should be remembered that all variables except vanadium were eliminated by the method of procedure adopted.

Table 5 is included to show the relatively low toughness and shock strength of high carbon cast nickel chrome steel; and the fact that the Charpy value obtained from a heat treated forged nickel steel is about the same as that of the heat treated cast orbit steel.

Table 5

NICKEL-CHROME STEELS

Test No.	Heat	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 Inches	Per Cent Reduction of Area	Charpy Kgm.	Charpy Ft. Lbs.
2327	C4251	0.51	0.39	0.71	0.051	0.045	2.85	0.87	1,550—4—AC 1,250—6—SC	108,000	72,000	17.5	24.8	1.083	7.85
2326	C4226	0.54	0.35	0.77	0.049	0.044	2.97	0.88	1,550—4—AC 1,250—6—SC	128,000	80,750	12.5	11.5	0.758	5.48
2325	C4218	0.60	0.33	0.67	0.04	0.041	2.81	0.92	1,550—4—AC 1,250—6—SC	116,000	90,000	15.0	21.7	1.22	8.82

FORGED NICKEL STEEL

C.	Si.	Mn.	S.	P.	Ni.	Heat Treatment*	Tensile Strength	Elastic Limit	Per Cent Elongation in 2 Inches	Per Cent Reduction of Area	Bend	Charpy Kgm.	Charpy Ft. Lbs.
0.35	0.16	0.50	0.019	0.012	2.96	Oil Q. and draw	86,500	53,500	27.2	52.5	180	2.809	20.35

*See Table 1 for heat treatment symbol key.

Endurance Tests Made on Farmer Type Machine

In Table 6 and Figs. 3 and 4 are given the results to date of endurance tests made in a Farmer type machine as modified by the University of Illinois Engineering Experiment Station. For these tests, six bars cut from three coupons of each type of steel were subjected to various loads, the tests being continued in each case at a constant load until the bar broke, or until it had withstood at least 10,000,000 alternations of stress. Certain of the test bars were afterwards put back in the machine and run at the same load, either to failure or until they had withstood 20,000,000 revolutions.

Table 6

ENDURANCE TESTS

Heat No.	C.	Si.	Mn.	S.	P.	Heat Treatment†	Fibre Stress	Revolutions 1st Run	Revolutions 1st and 2nd Runs
C4097	0.27	0.32	1.66	0.071	0.044	1,650—4—SC	55,835	182,800	....
							45,380	1,352,000	....
							45,325	1,801,300	....
							44,259	*16,064,000	16,358,600
							42,735	*10,532,000	18,714,100
C4097	0.27	0.32	1.66	0.071	0.044	1,650—4—AC 1,250—6—AC	68,389	8,900	....
							58,483	101,300	....
							48,431	855,900	....
							45,805	1,245,300	....
							43,677	*11,837,100	14,598,400
C94392	0.25	0.37	1.40	....	....	1,650—4—AC 1,250—6—AC	44,767	3,220,900	....
							43,920	*10,074,000	11,640,200
							43,543	*13,486,900	*21,433,300
C94392	0.25	0.37	1.40	....	....	1,650—4—Q 1,200—6—AC	49,077	3,013,800	....
							47,690	5,360,900	....
							47,547	*10,003,600	14,298,400
C4469	0.37	0.36	0.92	0.072	0.055	1,650—4—SC	43,543	1,356,600	....
							42,035	1,937,300	....
							39,773	2,853,800	....
							38,657	13,432,700	....
							38,265	*15,555,400	16,325,800
							37,922	10,470,900	....
C4613	0.28	...	0.77	0.078	....	1,650—4—SC	35,913	1,064,200	....
							34,495	1,711,000	....
							33,718	*20,000,000	....
E11	0.33	0.34	0.64	0.058	0.036	1,650—4—SC	35,242	8,530,300	....
							34,595	11,049,500	....
							34,495	*21,575,500	....

*Unbroken.
†For key to heat treatment symbols see Table 1.

The endurance limit of the orbit steel in the "annealed" and the "air cooled and drawn" conditions is from 42,000 to 43,000 pounds per square inch; in the "quenched and drawn" condition, about 46,500 pounds per square inch. Plain annealed cast steel of .37 per cent C. gives an endurance limit of about 37,000 pounds per square inch, and similar steel of .33 per cent carbon

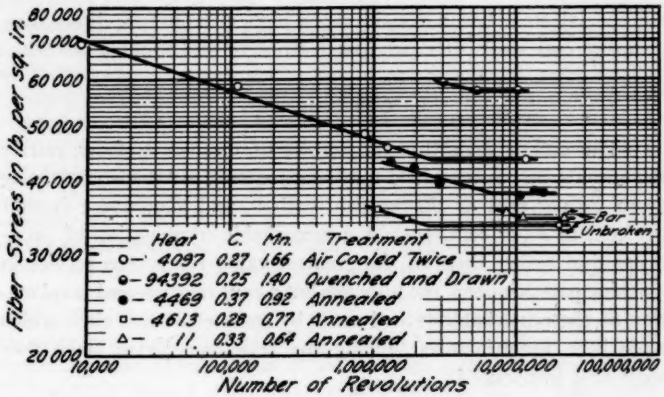
80 000
70 000
60 000
50 000
40 000
30 000
20 000
Fiber Stress in lb. per sq. in.
Heat C. Mn. Treatment
4097 0.27 1.66 Air Cooled Twice
94392 0.25 1.40 Quenched and Drawn
4469 0.37 0.92 Annealed
4613 0.28 0.77 Annealed
11 0.33 0.64 Annealed
Bar Unbroken
10,000
100,000
1,000,000
10,000,000
100,000,000
Number of Revolutions

FIG. 3

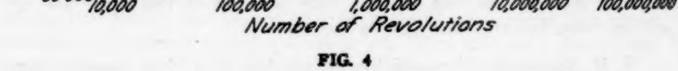
60 000
50 000
40 000
30 000
Fiber Stress in lb. per sq. in.
Heat C. Mn. Treatment
4097 0.27 1.66 Annealed
94392 0.25 1.40 Air Cooled Twice
Bar Unbroken
10,000
100,000
1,000,000
10,000,000
100,000,000
Number of Revolutions

FIG. 4

about 34,000 pounds per square inch, and of .28 per cent carbon about 33,000 pounds per square inch. Although the program of endurance tests is yet far from completed, it is felt that already sufficient data have been accumulated to justify the inference that the special steel has a considerably higher endurance limit than ordinary cast steels of much lower strength and toughness.

Conclusions

The author feels that the results of these tests fully justify the opinion he has long held that heat treated cast steels containing from .20 per cent to .30 per cent carbon, and manganese from 1 per cent to 2 per cent, possess a remarkable combination of properties that makes them of the greatest value for severe service in machine parts; indeed, the tests are but a confirmation and explanation of the remarkable record made by castings of this class which have been manufactured during the seventeen years since they were first introduced.

Discussion

Chairman A. H. Jameson: Gentlemen, this is a very valuable contribution to our knowledge of a subject which has been becoming more and more important in the steel casting industry, one in which Mr. Hall himself was not *a*, but *the* pioneer, I believe, and we are hearing the latest word from the man who, according to my information, knows most about it. I would like to ask Mr. Hall the methods of manufacture of the steel or the process used. I did not see these mentioned, as I read the paper rather sketchily.

J. H. Hall: I kept off that subject on purpose; I thought possibly somebody would ask it. Under the heat number in all these tables is either a "C" or an "E." The "C" means "Converter," side blown or bottom blown, and the "E" means "Basic Electric." You will also notice that some of these tests do not show very high elongation and reduction of area on some of our steels. That will prove that they are not selected tests, but are taken just as they came.

S. R. Robinson: I would like to ask Mr. Hall if he has any comparative tests on vanadium steels compared with the high manganese on the air quenched and drawn. I would also like to ask if he would tell us the method of adding the ferro-manganese to the metal for the higher manganese. We seem to have some trouble in getting a manganese content

of over 1 per cent by plunging the manganese. I wondered if he melted it previously.

J. H. Hall: Answering Mr. Robinson's first question, we made no comparative tests between the high manganese and the vanadium steel, air quenched and drawn. The amount of material at our disposal was limited and we took one end of the range, a plain anneal, and the other end of the range, a quench and draw, for our comparison, and we think it is fairly sure that the air quench and draw, which is intermediate, will follow about the same rule.

The method of adding the ferro-manganese for the high manganese steel in the converter is the same as has been mentioned in Mr. Hamilton's paper. The ferro-manganese is wet in a pail of water and thrown into the converter, the sudden generation of the steam blows the slag aside and lets the ferro-manganese into the metal. As Major Bull says, it is necessary to keep the size of the lumps fairly uniform, and, as Mr. West brought out, the volume of the slag and the timing of the operation must be kept correct. But we do have some variation. One time we will get 1.40 per cent manganese, the next time we may get as high as 1.60 per cent with exactly the same addition. But if we keep our carbon between .20 and .30, apparently quite a wide variation in manganese doesn't make much difference. A 0.28 carbon and 1.40 manganese and a 0.28 carbon with 1.70 manganese will give pretty close to the same results. The variation doesn't worry us so much if the manganese is well up around 1.40.

C. M. Campbell: In connection with Mr. Hall's last statement, I might say that on running some physical tests on manganese steels that averaged .50 carbon and 1.50 manganese, the physicals ran practically the same throughout. With the carbon between .50 and .55 per cent, and the manganese 1.50 to 1.75 per cent, the physicals showed hardly any change over the 25 point range in manganese.

R. W. Schlumpf: I would like to ask Mr. Hall if he had any trouble in quenching these high manganese castings, especially in heavy sections, say from 6 to 12 inches.

J. H. Hall: Mr. Schlumpf's question is an old one and perfectly well taken. In 1913, I think it was, I appeared before the American Society for Testing Materials and talked about quenching castings, and some of the older members said that of course that was interesting as a laboratory procedure, but they rather insinuated that anybody who would talk about quenching real castings needed a strait-jacket. They told me I was a "very fortunate young man" to have quenched a casting without cracking it.

Up to about two or three inches thick the castings can be quenched dead cold, in cold water, and then removed to the furnace and carefully reheated. When they get up around 6 or 8 inches thick, such as Mr. Schlumpf mentions, it is not possible to quench the castings down dead cold

in water. If you do, you will "hear the church bells ring" in the tank, the castings cracking on the inside. In those cases we adopt a procedure that we got from the late John Calder of the Pennsylvania Steel Company, as it then was, at Steelton, who was the first man that I know of who made commercially locomotive frames, quenched and drawn. He was making them of Mayari steel of about .30 carbon, with nickel and chrome, and he quenched and drew them by the simple process of quenching them until they were black but not cold and then withdrawing them from the tank and putting them in the second furnace for drawing, the second furnace being warm, almost red hot, when the castings were put in. Mr. Calder is dead now and his work was but very little known outside of Steelton, but he was a fine old gentleman, and we have adopted that practice with castings such as Mr. Schlumpf speaks of, 6 or 8 inches thick. In the majority of cases, however, steels of this sort, which are to be quenched and drawn, will be in light castings. We have been forced in our work to use this steel, quenched and drawn, in some castings that are as heavy as 6 inches by 8 inches, because every other steel that we put into those castings was unsuccessful. They were for steam shovel teeth, and the operators would break them, and for the main part of a heavy steam shovel tooth, the only successful material is this orbit steel, quenched and drawn. For the wearing end we use regular manganese steel.

R. W. Schlumpf: I want to mention an experience I had at the plant with which I am associated. We make chrome-nickel cast steel entirely, from .30 to .40 carbon, .45 to .75 chrome, and 1.00 to 1.50 nickel, and in experimental work we had to make a heat containing 1.25 per cent manganese along with the chrome-nickel. We gave it our regular heat treatment, which is a high temperature soak, two quenches and finally a low temperature draw, and we had about 115,000 yield point, 130,000 ultimate, 17 per cent elongation and 38 per cent reduction of area. We thought we had something pretty good. We found that later on, in trying to quench castings having a section of, well, I would say 4 to 5 inches, we couldn't quench them, they would crack every time. We found out that the high manganese was of no benefit in connection with chrome-nickel. We still successfully quench the same casting with chrome-nickel alone, not dead cold, but specified to be withdrawn from the quenching tank before the temperature drops below 350 degrees.

C. E. Sims: I would like to ask Mr. Hall if there was any tendency to warpage of the high manganese castings compared with carbon.

J. H. Hall: You mean, do these high manganese steels warp in quenching more than the low manganese? Not that we have ever observed.

C. E. Sims: Is there any improvement in the matter of warpage?

J. H. Hall: I wouldn't say so.

C. E. Sims: I haven't had any experience in quenching the high manganese castings. I have done some experimental work on the high manganese steels, running up as high as 4 per cent manganese, and carbons running from .10 to .35 and have found some very interesting results. The investigation is still in process and I am a little bit hesitant about giving any results as final because we don't know what we will get. But we have obtained in a forging a tensile strength as high as 209,000 pounds, with a 16 per cent elongation and 42.6 per cent reduction in area. We have also obtained Izod impact values up to 64 foot pounds.

J. L. Blair: Our specifications at the Industrial Works in our common steel are, on manganese, .75 to 1.00 per cent; on carbon I think it runs from .18 to .25. The foundry organization has felt for the last few months that, raising the manganese from, say .75 to 1.25 or 1.30 on castings that have a tendency to crack, that they would have less of a tendency to crack if we raised the manganese. I would just like to ask Mr. Hall how he feels about that.

J. H. Hall: I don't think we have any information on that. You mean less tendency to crack in the mold? I couldn't answer that question; I don't know that we have seen any less tendency to hot cracks with the high manganese than with the low.

J. L. Blair: I might also add, as Mr. Campbell stated, that really we have helped our test bars by getting a high manganese. With say .22 carbon, 1.30 per cent manganese, it raised the elongation and it raised the tensile strength, in fact, in some cases the elongation moved up quite a few points.

W. B. Perry: I was wondering if orbit steel had been made commercially for forgings in its soft condition, for instance, so that it might be forged into chains when soft and then given a quench and drawn to make it file hard to resist wearing.

J. H. Halls: When you say "orbit steel," you mean the steel that will air cool file hard?

W. B. Perry: Yes, sir.

J. H. Hall: That isn't what we call orbit steel. We have never made that steel commercially because, when file hard, that steel is exceedingly brittle. But steel of the orbit composition, about .30 per cent carbon and 1.50 per cent manganese, is being extensively pushed in forgings. I believe pretty near the whole rear end of the Buick is being made of steel of similar analysis, and I recently saw some information to the effect that these higher manganese steels lose strength less rapidly than the lower manganese steels when they are tested at increasing temperatures. They retain a higher percentage of their cold strength when tested, say, at 600 degree Fahr., than do steels of .70 manganese.

MAJOR R. A. BULL: In the paper that I read here yesterday I omitted reading the section relating to specifications, but I made a very brief comment verbally that I had argued in that particular section against the limitation on the manufacturer by the consumer of percentages of carbon, manganese and silicon in steel castings. I also mentioned in the paper itself something very briefly regarding the disposition of some consumers to limit the manufacturers to .85 per cent manganese. I presume a good many of us, if not all of us, are familiar with the fact that there are existing today certain specifications in which the manufacturer is limited to .85 manganese as a maximum. I think that Mr. Hall's paper is a very convincing argument that ought to dispel the illusions that some of these engineers have had that it is highly dangerous to use manganese over .85 per cent, and it seems to me that a number of us could do a pretty good job if we would send certain engineers we know marked copies of this paper. I think Mr. Hall, gentlemen, has made a very valuable contribution to our transactions.

CHAIRMAN A. H. JAMESON: If the Chairman may comment on Mr. Bull's remarks, or add his support to them, Mr. Bull is speaking of or perhaps has in mind the point that has been discussed and argued and fought very doggedly, and with some bitterness, in committees that have been sitting for the last two or three years. If this paper will help to fortify the members of this Association to fight, really to fight, the tendency to limit in specifications the chemical composition while at the same time imposing physical requirements, that alone would justify the paper.

Open Hearth Slags

By W. C. Hamilton,[1] East Chicago, Ind.

More than 25 years ago, it was recognized that to make good steel, the chief requirement was to form a good slag. Much has been written in recent years concerning open hearth slags and opinions differ greatly. At a temperature of 3000 degrees Fahr. reactions are taking place which have not been identified. A molten active slag is a different thing from the laboratory sample, and we resort to theories. Cause and effect lead us to certain conclusions, and give us our ideas concerning the relation between slag and steel.

In the open hearth practice there are two distinct processes, the acid and the basic. In the acid practice, sand is the essential factor. Sand or silica ($Si\ O_2$) is an acid radical giving the name acid open hearth process.

In the basic practice, a base is a necessity, hence the name basic furnace. Three basic materials are commonly used; i. e., magnesite ($MgCO_3$), dolomite ($CaCO_3MgCO_3$), and limestone ($CaCO_3$).

Acids and bases have opposite characteristics and unite very readily to form combinations which have entirely new properties. Therefore, it is difficult to discuss both acid and basic open hearth slags as one subject.

We should think of any open hearth slag in relation to:

1. The bottom of the furnace.
2. The bath of metal.
3. The flame in the furnace.
4. The deoxidizers and additions.
5. The steel in the ladle.

The acid practice is less complex and should first be considered.

1—Acid Slags

Protection is a chief function of an acid slag. The acid process is essentially an oxidizing one, but it is not a purifying process as is the basic.

[1]General Chief Chemist, American Steel Foundries.

The bottom of the acid furnace is made up of sand made dense by the addition of slag. The composition of the bath is governed largely by the materials charged and the influence of the flame.

The ordinary charge consists of cold pig and scrap. Iron ore (Fe_2O_3) is used as needed. Slag and sand are charged according to conditions. Oxidation is a necessity in order to eliminate the carbon, manganese and silicon. These elements, together with iron, act as reducing agents under certain conditions. It is therefore possible to have oxidation or reduction in progress in the bath and the metalloids may exist as a metal or as an oxide.

Knowing the composition of the initial charge and of the bath at frequent intervals, it is easy to check the progress of oxidation. The oxide of carbon escapes as a gas. The oxides of manganese, silicon and iron form a slag. We know that an acid slag is essentially a silicate of iron and manganese, MnO FeO $(SiO_2)_3$. There seems to be no reason to question the assumption that, in an acid slag the iron and manganese oxides exist as bases either free or in combination with silica.

Form of Oxide of Iron Doubtful

There is a doubt as to what oxide of iron exists, whether it is FeO, Fe_3O_4 or Fe_2O_3, or rather varying combinations of these oxides. It is true that metallic iron also may exist in the slag.

Silica

An acid slag consists approximately of 50 per cent silica and 45 per cent of iron and manganese oxides, together with other impurities, depending on the composition of the bottom material and the metals charged.

The supply of silicon from the metals is limited and the metallic oxides or bases formed by oxidation demand more silica than is available from the silicon in the charge, acquiring it from the bottom or from additions of sand.

An excessive oxidation of iron demands an increasing amount of silica. An equilibrium in the composition is closely maintained so far as bases and acids are concerned.

The proper addition of sand will, therefore, prevent silica being absorbed from the bottom. If the bottom is being robbed of silica, damage is done to it and there is a probability that part of the silica taken from the bottom will be trapped in the bath of metal. We thus may obtain our inclusions in the metal with their evil effects on the steel produced.

Slag Added to Bottom

As noted above, slag is added to the bottom of a new furnace in order to make it more dense. Unless this practice is followed, a great deal of molten metal from the first heat will penetrate into the bottom. This iron is gradually oxidized and will later react with the carbon in the bath. This reaction gives a boil. Every melter dreads such a boil as it is a warning of a dangerous condition. In extreme cases this boil may work a hole in the bottom and the loss of an entire heat from this cause is not a rare occurrence. At best, a boil of this kind will work impurities upward, which may later be the inclusions which cause a failure of the product. An acid slag is therefore needed as a protection to the bottom. This protection to the bottom in turn protects the metal.

Oxidation in Melting

When the flame strikes the cold charge, the first action is oxidation. Soon pools of metal begin to form. If about 20 pounds of slag per ton of charge has been added, a protection for these pools of iron is promptly formed. In addition, good supervision may suggest the use of sand to protect any bare metal in the early stages of melting. This protection is against oxidation and the absorption of sulphur from the flame.

When the bath is completely melted, a slag covering has been formed. As noted above, this slag is essentially a silicate of iron and manganese. Unless the silicon content of the charge was abnormally high, there is very little of this element in the molten bath. The silicon is oxidized in the melting down process and goes into the slag formation. The same is true as regards the greater part of the manganese.

The problem for the melter now is to eliminate by oxidation about .5 of a per cent of carbon. At the same time he must guard against excessive oxidation of the iron in the bath. This oxidation of the carbon may be done partly by using iron ore, but the final stages should be from the influence of the flame, through the slag covering. An extremely bulky and viscous slag does not permit the easy oxidation of carbon. Such a slag will trap the carbon monoxide (CO) and thereby hinder the passage of this gas. We then have a frothy slag. When iron ore is used, the temperature of the bath should be quite high or the gases formed are trapped and the frothy slag is obtained.

Color of Slag of Importance

The color of an acid slag, as seen on small pieces broken cold from a test spoon, is of great value in judging the condition of the slag and thereby the quality of the molten metal. A black slag indicates something is not right. A light colored slag is evidence of good quality.

The light colored slag can be changed to a black one in a few minutes by carrying a sharp oxidizing flame. It is not so easy to change the black slag to a light colored one. This change in color is no doubt due to the degree of oxidation of the iron in the slag. Unfortunately chemical analyses do not give much substantiation to this statement. The total iron oxides are no greater in a black slag.

It is assumed that FeO is the least harmful oxide of iron and that varying amounts of either Fe_2O_3 or Fe_3O_4 determine the color of the slag. Possibly the amount of metallic iron has a decided influence. Furthermore, whether the iron oxide exists in a free state or in combination with silica no doubt has a great bearing on the nature of the slag. Chemical or microscopic investigations so far have thrown very little light on this subject.

In order to obtain a light colored slag, it is the practice very often to add clay (Al_2O_3, $2SiO_2$, $2H_2O$), bauxite (Al_2O_3, $3H_2O$), or limestone ($CaCo_3$) with or without carbon. The alumina (Al_2O_3) in the clay or bauxite or the lime CaO will, as bases, replace a part of the iron oxide in the slag, provided the silica content is not sufficient to absorb the additional bases.

The iron oxide will be released and be thrown back into the bath of metal. Unless reduced, this iron oxide would be carried with the metal as inclusions into the finished products. It would, therefore, be possible to have a light colored slag, but with a badly conditioned bath of metal.

Unless this process of substitution is followed with extreme care, a very poor quality of steel may be produced. Often a melter will add limestone to a slag in order to thin it. If the slag is viscous, due to a high silica content, such an action is logical. However, the ordinary viscous slag is found not to be so on account of composition, but due to physical conditions resulting from some previous error of judgment.

Limestone added to correct this error will not permanently thin the slag. As the iron oxide is eliminated from the slag, the temporary fluidity is lost. It would seem that it is better practice for the ordinary heat to be made without the use of limestone or other substituting bases. Then the melter would depend on the proper control of his flame to obtain the light color in the slag.

A special practice is to reduce silica (SiO_2) from the hearth and transfer it as silicon (Si) to the bath of metal. A slag high in silica is necessary to accomplish this result, and it is good practice to use limestone in order to make such a slag more fluid. No substitution takes place, as an abnormal condition exists and the lime added will unite with the excess silica.

A slag in an acid furnace is the natural product of the process. Modifications of it, however, are easily made. While the slag is a protection to the bath, it must also act as an agent, transmitting the oxidizing action of the flame to the bath of metal.

Attempts have been made to eliminate phosphorus or sulphur by the acid practice, but so far nothing of practical value has been developed.

Open hearth slags present difficulties when certain additions are to be made to the steel in the furnace. Every one knows the great loss when chromium or manganese are added to the steel through the slag. This loss, however, can be reduced materially when the slag has been properly conditioned. Our efforts to improve the quality of the metal will reduce the loss of the additions.

When the steel is tapped into the ladle a covering of slag is necessary to conserve the heat in the steel.

2—Basic Slags

In the basic open hearth practice the slag is of even greater importance, as through it are eliminated large amounts of phosphorus and also sulphur to a less degree.

As sand (SiO_2) is the essential factor in the acid process, so are the oxides of magnesium (MgO) and calcium (CaO) in the basic.

The basic bottom is built up with burnt magnesite (magnesium oxide) or burnt dolomite (an oxide of calcium and magnesium). Slag is again necessary to obtain a dense bottom. Lime or limestone is charged in a definite proportion to the charge. From a metallurgical standpoint, limestone ($CaCO_3$) is preferable to lime (CaO) as a flux. However, from an economical view, lime has certain advantages.

Limestone

Limestone is a raw material and its composition is certain. Lime, in being calcined, is contaminated with sulphur from the fuel. Also the lime may not be perfectly calcined and therefore contain varying amounts of carbon dioxide.

Limestone when stored in the open is improved, as it disintegrates more easily when charged into the furnace. Lime must be protected from the weather, otherwise it will absorb moisture and carbon dioxide and give a disintegrated product of an unknown composition.

Limestone, when charged, must be calcined, which operation requires heat and time in the open hearth furnace. However, this calcining or elimination of carbon dioxide creates a desirable action in the bath of metal. It has been stated that this ebullition of carbon dioxide aids in the elimination of sulphur. It would appear, however, that this effect is apparent, but not real. Limestone free of sulphur would naturally give a lower sulphur bath than when lime is charged together with its contained sulphur.

The output of a basic open hearth furnace can be increased about 20 per cent when lime (CaO) is substituted for limestone ($CaCO_3$).

Volume of Slag Desirable

The volume of a slag desirable in a basic furnace is an open question. Amounts varying from 8 to 17 per cent of limestone are considered good practice, depending on requirements and

Table 1

Analyses of Slags

	Heat No. 1 16⅔ Per Cent Limestone ($CaCO_3$) Per Cent	Heat No. 2 4.3 Per Cent Lime (CaO) 7.8 Per Cent Limestone ($CaCO_3$) Per Cent
Silica (SiO_2)	11.00	13.58
Iron Oxide (FeO)	22.90	22.28
Manganese Oxide (MnO)	6.46	10.97
Lime (CaO)	48.87	42.92
Magnesia (MgO)	6.75	5.43
Phosphoric Acid (P_2O_5)	3.85	1.30
Sulphur (S)	.20	.16
Alumina (Al_2O_3)	....	3.91
	100.03	100.55

composition of the charge. The lower amounts result in reduction of time and in increased yields.

The chemical analyses of basic slags, formed by different charges of flux, do not vary greatly so far as the dominating constituents are concerned. The greater use of limestone will, of course, result in the better elimination of phosphorus and sulphur.

An interesting comparison is given in Table 1, which shows the effect of different amounts of limestone or lime on the composition of the slag and also on the melting loss in the furnace.

The charges for these two heats were radically different, which fact accounts for certain variations in the composition of the two slags. However, there is practically no difference in the content of iron oxide.

The following data on melting losses is of interest from an economical standpoint:

Heat No. 1 with 16⅔ per cent limestone ($CaCO_3$) had a charge containing 52 per cent pig iron.

Heat No. 2 with 4.3 per cent lime (CaO) had a charge containing 20 per cent pig iron.

Knowing the composition of the charge and by analyzing the residual in the bath, it is easy to determine the metalloids lost in the process. The metalloids lost in these two heats were:

Heat No. 1, 5.8 per cent.

Heat No. 2, 3.3 per cent.

In addition to the metalloids, we must know how much iron is lost in the process.

Table 2

Analysis of Dolomite to Make Bottoms

	Per Cent Lime (CaO)	Per Cent Magnesia (MgO)
Heat No. 1	56	40
Heat No. 2	50	30

Heat No. 1—6.75 per cent Magnesia x $\frac{56}{40}$ =9.45 per cent lime from bottom.

Heat No. 2—5.43 per cent magnesia x $\frac{50}{30}$ =9.05 per cent lime from bottom.

	Heat No. 1	Heat No. 2
Lime in slag (CaO)	48.87 per cent	42.99 per cent
Lime from bottom	9.45 per cent	9.05 per cent
Lime from charge	39.42 per cent	33.94 per cent
Lime (CaO) charged	4,666 pounds	2,180 pounds
100 per cent or weight of slag	11,827 pounds	6,423 pounds
Iron oxide as FeO	39.42 per cent or 2,710 pounds	22.28 per cent or 1,431 pounds
Iron in slag	2,100 pounds	1,109 pounds
Total metals charged, cold	53,520 pounds	52,090 pounds
Iron in slag	3.9 per cent	2.1 per cent
Metalloids lost	5.8 per cent	3.3 per cent
Iron in slag	3.9 per cent	2.1 per cent
Melting loss	9.7 per cent	5.4 per cent

It is assumed that all of the magnesia in the slag comes from the burnt dolomite used in making up the bottom. Knowing the content of lime and magnesia in this dolomite, it is a matter of proportion to convert the magnesia content of the slag into the amount of lime in the slag which had come from the dolomite.

The theoretical figures of Table 2 on melting loss have been substantiated by actual weights.

The data of Table 2 indicate the savings that can be made by a study of the materials charged into a basic open hearth furnace including the fluxes. Both of these practices are common ones and show a difference of 4.3 per cent in the melting losses. It should be noted, however, that coke is used in the No.

2 charge, and it is not included in the metals charged. It has been shown that a low fluxing charge will increase the yield and a reduction in time is also effected.

Amount of Lime in Charge

The amount of lime necessary will depend to a great extent on the amount of impurities in the charge. Sand adhering to castings charged will require extra lime. A well established practice is to add burnt lime during the refining period as it is needed to condition the slag.

Iron Oxide in Slag

The iron oxide in the basic slag, as in the acid slag, is the factor having the great influence on the quality of the steel. On account of other strong bases present, it is assumed that iron and manganese oxides in the basic slags may exist as either bases or acids. Granting this assumption, it is readily seen a basic slag may have its character changed at frequent intervals.

Unfortunately, the color of the cold basic slag is always very dark and gives no indication of the character of the slag. The basic melter must depend upon his skill in judging the slag as it exists in a molten state. Ordinarily, he is governed mostly by the consistency of the slag.

Lime will always make the slag more thick. Iron ore promotes fluidity, but its addition is limited by the carbon content of the bath and its temperature.

Use of Fluor Spar

The use of fluor spar (calcium fluoride) to confer fluidity to a basic slag is a common practice. It is well known that an addition of 50 pounds of fluor spar to a basic slag weighing 10,000 pounds will have a marked influence on the fluidity of the slag.

What reaction takes place has been considered by the writer for many years and some time ago a catalytic theory was advanced. This theory is best illustrated by the following equations:

(1)

$$\underset{\text{(Silica)}}{3\,SiO_2} + \underset{\text{(Calcium Fluoride)}}{2\,CaF_2} = \underset{\text{(Silicon Fluoride)}}{SiF_4} + \underset{\text{(Calcium Silicate)}}{2\,CaSiO_3}$$

(2)

$$\underset{\text{(Lime)}}{3\,CaO} + \underset{\text{(Silicon Fluoride)}}{SiF_4} = \underset{\text{(Calcium Fluoride)}}{2\,CaF_2} + \underset{\text{(Calcium Silicate)}}{CaSiO_3}$$

In reaction No. 1, the fluor spar (Calcium Fluoride) reacts with silica giving calcium silicate and silicon fluoride, a gas. A part of the silicon fluoride gas will no doubt escape. However, it is assumed that the greater part of it will react with lime as shown in equation No. 2. This reaction gives more calcium silicate and produces calcium fluoride, which would again take part in reaction No. 1, thus completing a cycle.

We have formed calcium silicate, a fusible slag and the fluor spar is simply an agent to produce this slag. Such an action would account for the very small amount of fluor spar which is necessary to change the consistency of a large mass of slag in the stage of formation.

Inclusions

While the basic reactions are quite different from the acid, nevertheless in both we have a process of oxidation. The problem in either case is to oxidize the metalloids without having an excessive oxidation of the iron. A slag in both processes is a necessity. It has its useful properties and its condition is reflected in the quality of the steel produced.

A combination of slag and steel in the finished product is fatal. Fortunately slag is much lighter than iron and there is a natural separation of the two materials in a molten condition. Too often, however, small globules of slag are trapped in the molten metal.

One of the great problems in the steel industry is to produce a product free of inclusions and these inclusions are to a great extent, particles of slag. Steel makers today realize the importance of slag in relation to the production of good steel.

There is open to technical men a great field of investigation in order to give to steel manufacturers more definite information concerning the slag reactions in open hearth furnaces.

Written Discussion—By E. R. Young

Mr. Hamilton's statement regarding acid slags, that the total iron oxides may be no greater in a black slag than in a light-colored slag, and that the color change is due to the degree of oxidation of the iron is very interesting and worthy of further discussion. I believe this is the first time this observation has been brought forward in a discussion of slag colors and slag analyses, and it offers quite a contrast to the analyses of lime-treated slags in which we are accustomed to consider the color as an index of the total iron oxides in the slag.

When limestone is added to an acid slag the resulting lighter-colored slag shows a lower content of iron oxide than the previous black slag, computing the total iron present as ferrous oxide (FeO). This indicates that there is less total iron, either metallic or in combination, in the lime-treated slag than in the black slag, as would be expected from the replacement of the iron oxide (FeO) in the slag by the lime (CaO).

Some of the English metallurgists* have shown that the amount of both FeO and Fe_2O_3 decreases in a lime-treated slag so that the color change in such a slag also may be due to a lower content of Fe_2O_3 rather than to the replacement of some FeO with CaO.

There seems to be a general agreement that we cannot make high-grade steel with a black slag, though we may make a light-colored slag without making good steel, especially if we resort to lime or other materials to secure the color change. Therefore, any information regarding the mechanism of this change in an untreated slag is of especial interest and it is hoped the question will receive further study.

Discussion

R. W. Schlumpf: Mr. Hamilton, have you ever had occasion to observe the characteristics of an acid slag when worked with finely ground ferro-manganese and the resulting characteristics of the heat or physical properties of the steel obtained?

W. C. Hamilton: Do you mean the addition of ferro-manganese before the heat is ready to be tapped?

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*Whiteley and Hallimond, Journal Iron & Steel Institute, 1919.

R. W. Schlumpf: In endeavoring to lower the iron oxide content of the slag, working the slag with, you might say, in a powdered form, ferro-manganese.

W. C. Hamilton: No, I have never used the powdered ferro-manganese. I have tried the lump ferro-manganese, probably an hour to an hour and a half before the heat is tapped, but I have never used powdered ferro-manganese in that connection.

J. L. Blair: I was quite interested in the discussion that came up yesterday morning in regard to whether it were possible to produce just as good steel in a 20-ton open hearth as in a 100-ton open hearth, and I would just like to ask Mr. Hamilton that question. Is it possible to produce just as good steel in a 20-ton open hearth as a 100-ton open hearth?

W. C. Hamilton: I would say absolutely, just as possible and more possible.

Mr. Coleman: Answering Mr. Schlumpf's question on ferro-manganese, during the war I handled the gun steel melting for Washington and at the Edgewater Steel Company we were making the 155 millimeter guns. When I arrived at the plant the heat was melted down in an extremely oxidized condition. We tried to save the heat and we used, not powdered ferro-manganese, but that which was crushed like gravel, probably from the size of hickory nuts all the way down to gravel size, and we gave it dose after dose. We would lighten up the slag, which was absolutely jet black and shiny, but you could not get the inclusions out of the metal.

For experimental purposes a 26 inch octagon ingot was put through fabrication and the transverse bar wouldn't pass, it was full of inclusions, even though we gave it four pretty heavy charges of ferro-manganese. It just seemed that the metal was so oxidized from the melting down that the ferro-manganese would not clear up the slag enough to cause the inclusions to pass from the metal into the slag.

I notice in the paper here the total iron oxide is no greater in a black slag. I don't know just exactly what that means, but what I have in mind is this. A number of years ago I had charge of the open hearth furnaces at Midvale, where we paid a great deal of attention to the analysis of the slag, and the physical appearance of the slag, on the acid open hearth. In gun steel melting you have to have a light slag; if you don't, you will never come through in your tests for submission. Now, I have found, at least, the laboratories have reported, not only at the Midvale plant but also at the various laboratories I visited during the War, a lower iron content in the slag, in the report I think it is FeO,—I will not argue with you whether it is FeO, or 2 or 3 or 4. That black slag that I mentioned at the Edgewater Steel Company ran something like pretty near 35 per cent of oxide of iron, while the light slag might run down to 15, and I have seen it down as low as 10. I just wondered when

I read this whether you are referring to something else, that is, "the total iron oxides are no greater in a black slag."

W. C. HAMILTON: We have made quite a number of analyses of different slags, of different appearances. In some cases of light color we have found lower iron oxides in the acid slag, in other cases we have not. In the basic process, where the iron oxide is lower, we have not been able to make any comparison between the color and the analysis at all, and we never have been able to pin down the light colored acid slag to a low total iron oxide content. Sometimes it does show lower, other times it shows higher, and we have ourselves not been convinced that we can assume that we have a good slag considering only the total amount of iron oxide.

MR. COLEMAN: How much manganese oxide do you carry in the slag, then?

W. C. HAMILTON: We have approximately 15 per cent.

MR. COLEMAN: How much calcium oxide?

W. C. HAMILTON: We do not ordinarily have any except what little may come from the bottom materials, less than one per cent.

MR. COLEMAN: You do not use any limestone?

W. C. HAMILTON: In our practice on the general run we do not; just on special heats we do; but my reference here was to slags without the use of limestone.

MR COLEMAN: What color, then, would your slag be? Would you get without the use of limestone what you call a light slag?

W. C. HAMILTON: If we watch the flame properly, we can get it to a tan color, a light tan.

MR. COLEMAN: But you do not get the greenish?

W. C. HAMILTON: We get a greenish hue, but the tan is predominating.

C. E. SIMS: I can corroborate Mr. Hamilton on the subject of the blackness of slag in relation to the iron oxide content. I think I can also throw a little light on it. There are two forms in which iron oxide can exist in an acid slag, as FeO, in which case it would form ferrous silicate, which is a light gray color, or, it can be in the form of Fe_3O_4. In the latter case it is not combined with the silica but is merely dissolved, because any oxide higher than the FeO does not combine with the silica. Fe_2O_3 cannot exist at those temperatures, that is, at temperatures at which the slag is molten, because it is not a stable form of the oxide at those temperatures. In analysis, of course, we determine FeO and Fe_2O_3, because there is no way in which Fe_3O_4 can be determined analytically. But if Fe_3O_4 is fused with silica, and allowed to crystallize, magnetite, or Fe_3O_4, will crystallize out.

For instance, a good example of that is found in open hearth practice. We find that the iron oxide fluxes get up and are deposited on inner

surface of an open hearth roof and cause it to flux and drip down. These drippings will have a very low melting point, but they will consist almost entirely of iron oxide and silica. However, if you allow these to crystallize and examine them petrographically, you will find there is only magnetite, and tridymite or cristobalite. Therefore, it would seem certain that the Fe_3O_4 is merely dissolved in the acid slag, but it lowers the melting point in the way that all substances do when they are added in small quantities.

I have found that in a black slag and a light colored slag containing the same quantity of iron, that the black slag will contain large amounts of Fe_2O_3. as shown by analysis, which, of course, exist as Fe_3O_4, whereas the light colored slag will show almost negligible quantities of Fe_2O_3 on analysis.

Mr. Hamilton's explanation of the action of fluorspar in thinning slag is rather interesting. Hitherto it has been generally supposed that fluorspar acts as a flux. For instance, we know that it will lower the melting point of most molten baths that it is added to. In the aluminum industry, where they use cryolite bath for dissolving aluminum oxide, fluorspar is added to increase fluidity. Although it is a fluoride bath already, it does have the effect of thinning it.

There is just one thing that isn't quite clear to me and that is as to just what form this silica is in that the calcium fluoride combines with in the first equation. It being a basic slag to begin with, it would be presumed to be there as calcium silicate or iron silicate to begin with.

W. C. Hamilton: I can't give any proof of those reactions. We have silica available from a number of sources in the basic furnace. We have the silica from sand that may be adhering to the stock or from the silicon that is oxidized from the metals that are charged, and we also have silica roofs. Mr. Sisco has brought out, I think, the reaction between the fluorspar and the silica of the roofs. Now, just what does take place here I am in no position to prove, but for a great many years the marked influence of a very small amount of fluorspar, say possibly 15 to 20 pounds, added to a charge consisting of 50,000 pounds of metal, and 15 per cent of limestone, has been a matter of great interest. I refer to an article that was published in Chemical and Metallurgical Engineering Magazine, I think in 1912. Professor Hoffman of the Massachusetts Institute of Technology replied to it and stated that, in his opinion, there is simply formed an alloy of a lower melting point. I never could see where such small amounts could have such a great influence, if it is simply a matter of forming an alloy of a lower melting point. It is a subject that I hope will be discussed, if not here, later on, to see whether or not any good reason can be given for this catalytic theory. I hope to later on go into it more thoroughly myself to see whether proofs may or may not be obtained.

Some Physical Properties and Compositions of Cast Converter Steel

By C. M. Campbell,* Cleveland, O.

The production of light steel castings has advanced rapidly since the invention of the side blown converter by Tropenas in 1891, and, in the past 12 years attention has been concentrated upon the job of getting the highest possible quality steel—which means highest possible yield point and ductility figures from the metal in such castings.

High physical characteristics are now obtained, especially good ductility is possible in cast steels that are dense, low in sulfides, oxides and other solid non-metallic impurities. That such results are possible is shown by the data of Tables 2, 3 and 4, which give average physical properties and compositions of converter steel made in the plant with which the writer is connected. Not only are the individual heat compositions held within close limits, as shown in the tables, but carbon, manganese, silicon and sulphur in any one heat are held very uniform throughout the whole heat. That this is so is seen by a study of Table 1.

Table 1

UNIFORMITY OF COMPOSITION IN HEATS

Heat No.	Date	Time	Per Cent Carbon	Per Cent Manganese	Per Cent Silicon	Per Cent Sulphur
2	6/29/26	After first shut off	0.25	0.58	0.29	0.046
2	6/29/26	Last ⅛ of ladle	0.24	0.56	0.30	0.040
4	6/29/26	After first shut off	0.25	0.58	0.29	0.040
4	6/29/26	Last ⅛ of ladle	0.26	0.56	0.30	0.042
8	6/29/26	After first shut off	0.21	0.65	0.34	0.040
8	6/29/26	Last ⅛ of ladle	0.22	0.66	0.35	0.042

Time for charging steel from converter into ladle to opening up in foundry was for heat No. 2—5 minutes; heat No. 4—7 minutes; heat No. 8—5 minutes.

Temperatures of these heats at time of opening up as determined by an optical pyrometer were for heat No. 2—2,905° F.; heat No. 4—2,910° F.; heat No. 8—2,900° F.

Blowing Procedure

The converter process for making steel is essentially an oxidizing operation. Highly heated FeO produced by action of O upon Fe by blowing air over the surface of the liquid metal is reduced either wholly or partly by the manganese and silicon in the bath. MnO and SiO_2, or, more likely, SiO_3Mn or SiO_3Fe are

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formed, which are less soluble than FeO in the molten iron. Since FeO is soluble in molten iron, its saturation point is about 1 per cent at the melting temperature of the iron. The presence of manganese and silicon, and the agitation of the bath against the silica walls of the converter, will lower this saturation point well below 1 per cent.

During the carbon boil, it is probable that little, if any, of the remaining FeO is reduced. Although FeO is reduced by C, the reaction can work both ways and Fe and FeO can exist together in the presence of C. At the finish of a blow, the slag is rather viscous and contains some 55 per cent to 60 per cent SiO_2. Such a slag is not oxidizing but will absorb FeO from the metal. However, the small amount of FeO remaining in the bath is reduced by addition of recarburizers.

During the reactions between FeO and Mn and Si, it would seem that oxidation products of a very finely divided form were produced and widely dispersed in the metal. In such form it would be difficult for them to pass into the slag, unless the metal was agitated against the slag or sufficient time allowed for minute particles of oxides to rise to the surface. In the converter, the agitation of the metal against the slag and silica side walls should, as in the crucible process, favor complete deoxidation.

Control of Sulphides and Non-Metallic Impurities

Since sulphides and other solid non-metallic impurities adversely affect the ductility of cast steel, it would seem, according to the physical properties shown in the tables, that such impurities are not present in harmful amounts in converter steel.

The lowest figures for elongation and reduction of area in the 0.15 to 0.20 per cent carbon steels as cast are 25 and 50 per cent respectively; for the 0.20 to 0.28 per cent carbon steels as cast, they are 15 and 18 per cent respectively; and for 0.40 to 0.50 per cent carbon steels as cast, they are 11 and 15 per cent.

Desulphurization and Deoxidation

Desulphurization in the basic electric furnace is accomplished with a white lime slag containing calcium carbide and it is possible to reduce sulphur to very low limits, oftentimes below 0.010%.

At the time this became known, it was thought that very high grade steel would be produced in the electric furnace on account of its strong desulphurizing and dephosphorizing power, but when such pure metal was actually made it was found to be inferior to acid open hearth steel of like composition. If steel of such low sulphur and phos. content did not show expected results, it is certain these elements are not detrimental as they were thought to be.

What, then, is the cause of the trouble?

According to investigators, it is thought that finely divided submicroscopic impurities act as nuclei for the concentration of other constituents, which, in turn, have detrimental effect upon the physical properties of the steel. As stated above, these non-metallic impurities must be removed from the metal to the slag, and, in the converter process, it is likely that elimination proceeds in the manner already stated.

Just how far this operation must go in order to assure a sound steel of maximum ductility and toughness has not been determined. At present, there are not any methods or apparatus developed for this purpose that can be applied in a works laboratory.

Several years ago, the writer attempted to determine the O content of converter steel and its relation to the physical properties. The data obtained are given below:

	O	O	O
Average of 11 heats	—0,036%	0.053 Max.	0,022 Min.

Average tensile test—11 heats

T. S.	E. L.	Elong. in 2"	Red. of Area
70,000 lbs. per sq in.	40,000 lbs. per sq. in.	28%	45%

Average analysis—11 heats

C	Mn	Si	S
0.20%	0.65%	0.35%	0.05%

This analysis does not indicate how the O was combined in the metal but when expressed in terms of iron oxide, the figures would be

0.036–0.162	0.055–0.25	0.022–0.099

Conforming to the usual specifications does not necessarily guarantee a higher quality steel, and, upon what has been stated above, the desired qualities may be obtained when we can determine, in exact figures, the amounts of impurities other than sulphur and phos. that are to be removed from the metal.

Table 2

PHYSICAL PROPERTIES OF CONVERTER CAST STEEL IN THE ANNEALED AND UNANNEALED STATE

Carbon Per cent	Condition	Tensile Strength, pounds per square inch	Yield Point, pounds per square inch	Per cent Elongation in 2 inches	Per cent Reduction in Area
(A)—0.15 to 0.20	as cast	60,000	33,700	30.0	50.0
	annealed	60,000	34,600	37.5	54.0
(B)—0.20 to 0.28	as cast	72,000	41,000	18.0	25.0
	annealed	72,000	42,000	30.0	46.0
(C)—0.40 to 0.50	as cast	95,000	54,450	12.5	18.0
	annealed	95,300	57,000	18.0	30.0
(D)—0.25 to 0.30, with High Manganese	as cast	85,400	56,900	20.0	28.0
	annealed	87,000	57,200	25.0	40.0

Table 3

COMPOSITION OF CONVERTER CAST STEEL

(Phosphorus under 0.04 per cent)

		Carbon Per cent	Manganese Per cent	Silicon Per cent	Sulphur Per cent
(A)—Composition, 7 heats; March, 1926; Carbon range 0.15 to 0.20.	Average	0.16	0.73	0.33	0.052
	Maximum	0.17	0.80	0.40	0.053
	Minimum	0.15	0.66	0.30	0.049
(B)—14 consecutive heats; April, 1926; Carbon range 0.20 to 0.28.	Average	0.25	0.73	0.39	0.047
	Maximum	0.28	0.79	0.41	0.053
	Minimum	0.22	0.67	0.32	0.041
(C)—19 consecutive heats; March, 1926; Carbon range 0.40 to 0.50.	Average	0.47	0.73	0.36	0.048
	Maximum	0.50	0.78	0.40	0.050
	Minimum	0.42	0.70	0.32	0.042
(D)—1 heat, High Manganese Cast Steel; Carbon range 0.25 to 0.30.	....	0.28	1.14	0.38	0.041

Table 4

COMPOSITION OF SPECIAL CAST MANGANESE-VANADIUM CAST STEELS

9 Heats—November, 1925

	Per cent Carbon	Per cent Manganese	Per cent Silicon	Per cent Sulphur	Per cent Phosphorus	Per cent Vanadium
Average	0.56	1.62	0.53	0.038	0.04 or under	0.18
Maximum	0.59	1.77	0.55	0.025	0.04 or under	0.15
Minimum	0.54	1.57	0.46	0.046	0.04 or under	0.27

The practice of testing the steel "as cast," has the advantage of readily showing up the character of the steel making and casting operations. Steels "as cast," having elongation and reduc-

tion of area much below the minimum figures shown above, may contain too many impurities or be cast too hot, and it would be difficult to secure the desired physical properties in the annealed condition.

Manganese

The effect of increasing manganese within certain limits in steel of a given carbon content, is to increase its yield point and ductility.

It is sometimes desirable to secure a higher yield point and ductility in certain castings, and this can be done by increasing the manganese instead of the carbon, as shown by comparison of Sections C and D of Table 2.

A 0.28 carbon and 1.14 manganese steel has a yield point of 57,200 pounds per square inch as compared to a 0.47 carbon and 0.73 manganese steel having a yield point of 57,000 pounds per square inch; but the high manganese steel has an elongation in 2 inches of 25 per cent and reduction of area of 40 per cent in the annealed state, as compared to lower manganese steel with an elongation of 18 per cent and reduction of area of 30 per cent.

Sulphur

The effect of sulphur in amounts of 0.07 per cent and greater is to cause hot cracks in steel castings of thin sections and complicated shapes. Sulphur under 0.07 per cent does not have this effect upon steel castings, neither does it affect the physical properties. Between 0.07 per cent and 0.05 per cent sulphur, the effect upon the machinability of steel castings seems to be to increase its free cutting properties. Sulphur, in these small amounts, probably occurs entirely as manganese-sulphide in globular form in the steel, and is thereby rendered harmless to the metal.

In the converter process, sulphur is reduced by treating the iron in the ladle with fused soda ash. By adding an amount equal to ½ of 1 per cent of the weight of iron in the ladle, sulphur is reduced to between 0.07 and 0.05 per cent. An amount equal to 1 per cent of the weight of iron in ladle reduces sulphur to

between 0.05 per cent and 0.035 per cent, and sometimes as low as 0.025 per cent.

The larger part of our output of castings is made to specifications which limit us to 0.05 per cent sulphur as a maximum, and we have been doing this regularly since the last quarter of 1923.

Data on General Converter Practice

Cupola charges:

400 pounds low sulphur, low phosphorus pig iron—first 8 charges.
400 pounds steel scrap and 400 pounds foundry scrap alternately—first 8 charges.
320 pounds high silicon steel scrap—(Silicon 2.00 to 4.00 per cent).
240 pounds steel scrap—forging tong holds, plates, etc.
240 pounds foundry scrap—heads and gates—our own.
150 pounds coke.
45 pounds limestone—97 per cent to 98 per cent calcium carbonate.

Converter operation:

Converter will blow 4000—4500 pounds hot metal.
Blowing time—16 minutes—average.
Blowing loss 14 per cent—average.
Cupola melting loss 5 per cent—average.

Recarburization

For 0.15 to 0.20 per cent carbon steel the blown metal is recarburized by adding 80 per cent ferro-manganese and 50 per cent ferro-silicon to the steel in the ladle. For 0.20 to 0.28 per cent carbon steel, we add silico-spiegel to the metal in the converter either melted or cold, and balance of manganese and silicon is added to the steel in the ladle. For 0.40 to 0.50 per cent carbon steel we add melted silico-spiegel to the metal in the converter, and the balance of manganese and silicon is added to the steel in the ladle.

Pouring

Bottom pouring steel ladles are used for casting purposes in the foundry, the heavy dry sand castings being poured from this ladle and medium weight and light green sand castings being poured by means of shank ladles.

Table 5

ANNEALING METHODS

Annealing Method No. 1—Light Weight Thin Section			
0.15 to 0.28 carbon steel	Heat 2 hours to 1,650 degrees Fahr.	Hold 1 hour 1,650 degrees Fahr.	Air cool 0.15 to 0.20 carbon steel castings. Furnace cool 0.20 to 0.28 carbon steel castings
0.40 to 0.50 carbon steel	Heat 2 hours 1,600 degrees Fahr.	Hold 1 hour 1,650 degrees Fahr.	Furnace cool
Annealing Method No. 2—Heavy Section (One Inch and Over)			
0.15 to 0.28 carbon steel	Heat slowly (about 400 degrees) to 1,650 degrees Fahr.	Hold at 1,650 degrees Fahr. 1 to 3 hours	Furnace cool
0.40 to 0.50 carbon steel	Heat slowly (about 400 degrees Fahr. per hour) to 1,600 degrees Fahr.	Hold at 1,600 degrees Fahr. for 1 to 3 hours	Furnace cool

Annealing

We have two annealing procedures. These are given in Table 5. Method No. 1 is used for light weight and thin section steel castings, while method No. 2 is used for heavy section castings (1 inch and over in thickness). We do not ordinarily use other methods of heat-treating castings except in certain cases where a method of heat treating is worked out for these special cases.

Discussion

R. W. Schlumpf: I would like to ask Mr. Campbell how the test pieces were taken from which these particular physical properties were obtained.

C. M. Campbell: The test pieces are cast separate from the casting. We use a section of about 3 inches in diameter and eight to ten inches long, having three lugs. This is bottom poured, that is, with a horn gate, and a head suitable to take care of the shrinkage. This is poured in either dry sand or green sand, whichever is to be desired at the time.

J. L. Blair: It was my good fortune just about six months ago to visit the West Steel Casting Company plant and I noticed that they plunge the manganese, as Mr. Campbell states in his paper, but I didn't pay particular attention as to whether they had any particular way of plunging it. In looking over Table 3, I notice how uniform the manganese seems to be, in the different heats that he has, and I just wanted to ask him if he had any particular way of plunging the manganese.

C. M. Campbell: We have no particular way of doing it. The manganese and any other cold alloys are placed in water and charged in under the slag by just simply tossing into converter in usual manner.

J. L. Blair: There is no way of removing the slag, then?

C. M. Campbell: No, we don't attempt to remove the slag. The water on the alloy, of course, blasts the slag away, the alloy sinking into the bath of metal. I presume that one reason for uniformity in a case of this sort is, that the amount of slag on the metal is very light. That is, for a 4,000 to 4,500 pound blow we get approximately 150 pounds of slag in the converter, so you see, it forms a rather thin layer, and, immediately the converter is pulled down, although the slag contains some 55 per cent silica, it is hot and at that time rather thin; it becomes viscous later.

J. L. Blair: I want to say that we seem to go off just once in a while on the blow. We plunge our manganese just as Mr. Campbell has said, but once in a while we seem to go off, it seems to drop or seems to go up. We probably have 7 or 8 blows a day and there is always one of them that seems to spoil the day.

Major R. A. Bull: It just occurred to me that a partial answer to that might be the size of the pieces of ferro-manganese. I believe if the manganese additions are selected as to size, with a fair degree of uniformity, it does add to the uniformity of the resulting content of manganese. In other words, if you have very small pieces, and other big chunks the size of a couple of fists, I think you would have a difference. On the other hand, if your pieces are sized within a reasonable degree, I believe that your effects are more nearly constant.

R. West: I would like to enlarge a little bit upon Mr. Campbell's explanation there in regard to Mr. Blair's question. I think the main reason for our uniformity in our result there is obtained from the rapidity of our operations. In checking up in detail we found out that the time varied considerably between the cupola metal going into the converter, the converter metal coming out of the converter and going into the ladle and getting into the foundry, so we ran a series of tests for time elements and we found we were able to cut the time in two in all these operations. That was a very vital factor in getting absolute and correct analyses, especially

in the throwing of the lump manganese into the converter. If you are delayed there at all, your slag will thicken up on you quickly and you will not get the proper mixture or the proper manganese into your mix. You must follow that operation there right down to the second or the minute, as closely as possible, so as to get a complete immersion.

Another very important practical point there, you spoke about possibly being off one heat during the day's run. In the past we also found that condition and every time we went into it we found we had excessive slags, heavy slags, and in that case we found it was the converter linings and immediately ordered new linings in the converter. In other words, it was a question of keeping your lining in your vessel always up to a practical condition so that you wouldn't have heavy slags from the loss of converter linings. Those two points, one, quick operation and the other your lining, give you a regularity in your analysis.

S. R. Robinson: I would like to ask Mr Campbell how he melts his silico-spiegel.

C. M. Campbell: We use a reverberatory oil-fired furnace. The melting loss was found to be not over 5 per cent total.

Mr. Coleman: I would like to ask Mr. Campbell how much silicon he adds to the metal.

C. M. Campbell: For a 4,000 pound heat, it amounts to, on a 14 per cent blowing loss, 26 to 30 pounds of 50 per cent ferro-silicon.

Mr. Coleman: What would that be in points? Do you know, offhand?

C. M. Campbell: That gives us a range of between .30 and .40.

Mr. Coleman: In other words, you get pretty near what you add.

C. M. Campbell: Almost.

Mr. Coleman: Have you ever experienced heats where you have had a residual silicon in the converter of probably .25 to .30?

C. M. Campbell: Yes, but not during the past two years. It occurred at times, I believe, where silicon would run even higher. Sometimes we would get .50.

Mr. Coleman: That is without the addition of silicon?

C. M. Campbell: Without the addition of silicon. But I have noticed in cases where this occurred the heat was most generally blown short, or, if the heat was blowing too fast, would get a rapid silicon boil, heating the bath to a temperature where oxygen would grab the carbon before all silicon was consumed, at which time a carbon boil would start.

If this carbon boil is allowed to continue to the drop of the flame, the heat would finish with excess silicon. However, if you keep your

silicon down in the iron, that is your cupola iron can be not over 1.25 silicon, and very hot, say around 2,650 degrees Fahr., you will very likely not experience this trouble.

Mr. Coleman: I have noticed that trouble in converters and I had thought probably it was due to some of the high temperatures of the metal giving a reversal of reactions similar to the action in the acid open hearth furnace.

C. M. Campbell: Yes, that action is the same.

Report of Committee on Steel Castings

To the Members of the American Foundrymen's Association:

During the past year there has been no change in the substance of any accepted specifications of steel castings.

This does not mean, however, that there has been no work performed, or that the committees of various bodies concerned in the steel castings have been idle. The A.S.T.M. committees have held their meetings and discussed minor points mostly of form rather than of substance. The general specifications for steel castings have been modified not at all. The tentative specifications for steel castings for high temperatures known under the name of A95-25T have been the storm center of a good deal of discussion and debate. Several meetings were held, all of which were attended by representatives from this committee. The final result was that the specifications above referred to continue as tentative for another year, but the committee has been charged with investigating with the advisability of framing specifications for steel castings for service to 1,000 degrees Fahr. and to 1,200 degrees Fahr.

Specifications A95-25T have been definitely confined to application for uses where the temperature runs not over 750 degrees Fahr. It is felt that there is a need for material for higher temperatures. The A.S.T.M. committee is to investigate this and your committee wishes your interest and assistance. There is none too much information available, and we urge most strongly that every member of the American Foundrymen's Association who has recorded data, or experience which has a bearing on the subject, should place it at the disposal of your committee. The engineers are demanding material which will stand more severe service: they look to us foundrymen to supply it.

Other than this, we can report only that the other specifications now in use seem to be meeting with more or less satisfaction so that there is no strong demand for change or amplifications. The committee welcomes suggestion or criticism, however, and

we hope that we are not to complacently assume a satisfaction which perhaps is not universal.

The foregoing, you see, is again our opinion for your assistance. Your interest in the matter, we cannot doubt. Cannot you strengthen your committee's influence by showing this interest in a tangible way by contributing your own experience and advice?

Respectfully submitted,

A. H. Jameson,
Chairman.

Report of A. F. A. Representative on Joint Committee on Investigation of Effect of Phosphorus and Sulphur in Steel

To the Members of the American Foundrymen's Association:

1. Your representative on the Joint Committee on Investigation of the Effect of Phosphorus and Sulphur in Steel hereby reports on the activities of the Joint Committee since the last A. F. A. convention, in so far as these activities relate directly or indirectly to steel castings.

2. Attention is directed to the report of the Joint Committee presented at the convention of the American Society for Testing Materials, June 21, 1926, at Atlantic City. In that report the following statements appear:

"Publication of the conclusions drawn by the Joint Committee from this investigation of rivet steel has been deferred until all data on this subject were in hand. It so happens that the study of several of the series of steels with higher carbon contents is well along towards completion, such that a background is given for strengthening or confirming the conclusions on rivet steel.

"It should be emphasized, however, that these conclusions may properly be considered valid only for the type of rivet steel used in this investigation, namely, a steel with a carbon range of 0.09 to 0.15 per cent, manganese 0.35 to 0.64 per cent, phosphorus 0.005 to 0.024 per cent, silicon 0.002 to 0.057 per cent, and sulphur ranging from 0.03 to 0.18 per cent.

"The sulphur present in commercial rivet steel up to at least 0.06 per cent is not detrimental, the tests showing no systematic relation between any of the physical properties determined and the sulphur content up to 0.06 per cent.

"For the following properties determined for material in the natural, annealed and quenched conditions, no systematic relation with sulphur up to 0.18 per cent is shown by these tests:

Tensile strength, proportional limit and yield point for material tested both parallel and perpendicular to direction of rolling; percentages of elongation and reduction of area for material tested parallel to direction of rolling; shearing strength; hardness, torsional properties; endurance limit; cold bend tests of bars; cold bending, hot flattening and hot and cold upsetting tests of rivets.

"Above sulphur of about 0.06 per cent, the values of the following properties decrease with increase in sulphur content: Percentages of elongation and reduction of area for material tested perpendicular to direction of rolling, in the three conditions, natural, annealed and quenched; Charpy and Izod impact tests for all three conditions of the material, tested parallel and perpendicular to the direction of rolling.

"The strength of riveted joints tested both in single shear and double shear decreases for increase in sulphur content of rivets above about 0.08 per cent.

"In conclusion, attention should be called to the remarkable agreement in physical properties found in the total of over 5400 measurements of the various physical properties carried out independently in the two laboratories that made the tests, Watertown Arsenal and the U. S. Naval Engineering Experiment Station. Finally, it is expected that the whole report containing all data in tabular form will be published by the U. S. Bureau of Standards."

3. The paragraphs above quoted are thought proper to include in this report to the A. F. A., because the data that resulted in the published conclusions of the Joint Committee were a large factor in eliminating the proposed sulphur tests on steel castings, to be referred to in this report.

4. In November, 1925, the Sub-Committee on Tests of the Joint Committee requested from steel foundrymen who were members of the Joint Committee, advice regarding suitable sulphur tests on steel castings. Your representative's assistant attended a meeting held to consider this subject at the Watertown Arsenal, November 17, 1925, following which your representative, on his own initiative with the cooperation of the officers of the A. F. A. and the Steel Founders' Society, arranged for the formation of a small temporary advisory committee of repre-

sentative steel foundrymen, so that the opinions of these men, rather than the views of the few steel foundrymen on the Joint Committee, might be made the basis for action by the Joint Committee, regarding tests on steel castings. The temporary committee held a meeting in New York, February 18, 1926, attended by Dr. F. C. Langenberg of the Watertown Arsenal, Chairman of the Sub-Committee on Tests of the Joint Committee. The steel foundrymen present were as follows:

A. Walcher, American Steel Foundries.
W. C. Hamilton, American Steel Foundries.
E. W. Campion, Buckeye Steel Castings Co.
E. H. Stehman, Birdsboro Steel Foundry & Machine Co.
G. K. Elliott, The Lunkenheimer Co.
R. A. Bull, American Foundrymen's Association.

John H. Hall, of the Taylor-Wharton Iron & Steel Co., had expected to be present, but was prevented by illness. W. J. Corbett, Secretary of the Steel Founders' Society, was prevented from attending the conference because of a conflicting meeting of his Society in Pittsburgh. Mr. Stehman represented the Steel Founders' Society as well as the Birdsboro Company at the conference.

5. After thorough consideration of all phases of the subject, which had been partially clarified by correspondence prior to the meeting, the informal conclusions unanimously reached by the steel foundrymen present were as follows:

(A) The preliminary reports issued by the Joint Committee covering the effects of sulphur in rolled steels of various grades show the tests made on these steels to have been very comprehensive. These tests indicate no harmful effect on steel of a sulphur content as high as would be practical to employ in commercial steel foundry practice.

(B) There seems to be a satisfactory degree of consistency between the results of the residual sulphur tests and added sulphur tests.

(C) It appears that the injurious influence of a very high sulphur content is noticeable in proportion as the material is subjected to hot working; and that steel in the condition as cast may be reasonably regarded as not susceptible to harmful in-

fluences from sulphur within limits that would be commercially feasible to employ in the foundry.

(D) The average steel foundry, unlike many plants making steel products, for its own protection, irrespective of reasonably low specification limits, must produce metal having a sulphur content that is not excessive, because of red-shortness caused by high sulphur, and the resulting serious trouble in the foundry from shrinkage cracks in castings so designed as to present difficulties in the contraction of the members during solidification. The proportion of steel castings not susceptible to shrinkage cracks by reason of design is very small. A large percentage of the output of steel castings consists of railroad specialties. Generally, these are of such a nature as to require the foundry to maintain a low sulphur content to avoid excessive losses from shrinkage cracks.

(E) An investigation to determine the influence of sulphur on test coupons attached to blocks of the usual type for this purpose would, it is believed, simply confirm the results of laboratory tests heretofore made under the direction of the Joint Committee.

6. The Sub-Committee on Tests of the Joint Committee had strongly indicated its belief that any sulphur tests on the product of the steel foundry would be inconclusive unless they included tests to destruction of typical castings of specified design, containing increasingly large percentages of sulphur. It had been proposed that such tests supplement experiments on specimens cut from coupons cast as ribs on the customary type of test block. The foundrymen present at the meeting concurred unanimously in the opinion that an investigation into the performance under destruction tests of typical castings, to determine the influence of sulphur alone in such castings, would involve a tremendous expense and a very long time because of the extreme difficulty of making two castings exactly alike, even when all manufacturing details are carefully prescribed and followed strictly as far as possible. It was pointed out that all the factors involved in producing the slight differences that exist between two castings from the same pattern, would have an influence on the resistance of the casting to any testing procedure applied to determine the relative serviceability of the entire cast-

ing considered as an integer. Reference was made to the eight years that have transpired during the prosecution of tests of the kind mentioned on car couplers, not yet completed.

7. It was further pointed out that the serviceability of steel castings as it may be influenced by a red-short condition due to sulphur producing an interior rupture that might not be observable on the surface, would be extremely difficult to determine, because of numerous factors causing shrinkage cracks in steel castings, such as hardness of mold, hardness of core, position or design of gate or riser, filleting at intersections, design of flask, position or design of flask bars, pouring temperature, etc. It was emphasized that these and similar elements are so numerous and so incapable of becoming standardized practices that one foundry might successfully produce a given casting having steel containing .06% sulphur, while another foundry might not be able to produce the same casting without destructive shrinkage cracks, from steel containing .03% sulphur.

8. The foundrymen at the conference unanimously agreed that any comprehensive testing program would involve special expenses of large amount, and that any such expenses ought to be borne by assessments levied on companies in the industry. It was felt that a call for funds for this purpose, to be effective, would have to be accompanied by convincing arguments regarding the practicability and the commercial application of the investigation.

9. Based on the conclusions and recommendations of the temporary advisory committee of foundrymen as indicated in the foregoing, the Sub-Committee on Tests, and later the Joint Committee, decided definitely not to conduct any sulphur tests on the product of the steel foundry.

10. The Joint Committee, on August 23, 1926, requested your representative to ascertain the attitude of the A. F. A. on the matter of determining the effect of phosphorus in steel castings. A similar request has been made to the Steel Founders' Society. It is hoped that you will take sufficient interest in this inquiry to give your representative the assistance he would get from knowledge of your convictions. It should be remembered that the A. F. A. and the Steel Founders' Society are the only

foundry organizations holding memberships on the Joint Committee; and that each of these organizations is represented on the Joint Committee by one individual.

11. The undersigned, who endeavors to voice the opinions of steel foundrymen belonging to the A. F. A., hopes that those he represents will endorse the actions he has thus far taken, and the recommendations made by the temporary advisory committee of foundrymen which were the basis for the Joint Committee's elimination of the steel casting sulphur tests.

Respectfully submitted,

R. A. Bull,
Representative.

Discussion

Major R. A. Bull: Gentlemen, I would like for you to express yourselves on this subject. I might mention that the Steel Founders' Society has a meeting in this city on Thursday, and I have had some correspondence regarding this matter with Mr. Corbett, secretary of the society. He has a similar request from the Joint Committee, and I presume he is prepared to present that before the Society at that time. I wrote him recently, and I hoped it might be possible for him to be here today, in which case he could tell you whether or not the question has been considered by the officers of the Steel Founders' Society, or by its executive committee, prior to the meeting to be held next Thursday. I don't happen to know if the matter has been considered, even in a preliminary way, by the Society. It is very desirable that the A. F. A. and the Steel Founders' Society agree as to what should be done.

Chairman A. H. Jameson: I can speak feelingly for Mr. Bull's position. Being a representative of the A. F. A. on committees is a labor of love, if you choose so to call it. It is frequently difficult to get the active support of the Association to the extent of getting an expression of a definite opinion of the members. One can talk to half a dozen, but it is very likely to be the same half dozen that he sees frequently and with whom he discusses these matters. To go before a committee, as he has had to on a lot of this work, wondering whether he is giving his individual views or actually expressing the opinions of a large membership like ours, is difficult. He is entitled to more than a feeling of moral support, he is entitled to the assurance of it.

To put first the question that he has asked last, I will ask Mr. Galvin, who is an officer of the Steel Founders' Society, if he can give us any information as to the desire for cooperation which they feel, or whether any action has been taken as yet.

JOHN GALVIN: Mr. Chairman, I don't know what the Steel Founders' Society will do, but while certain engineers might criticize steel foundrymen if they don't want to support these tests, still as I am opposed to waste in industry, I think tests to determine the effect of phosphorus in steel castings are a waste of time. I believe it is pretty generally understood and proved that when the phosphorus goes up in the castings, they are brittle. We can see that in the cleaning room; when we get castings in which the phosphorus content is high, we find that the heads break off very easily. I see no reason for going ahead and wasting money and time trying to find out something that is an accepted fact, borne out by experience.

MAJOR R. A. BULL: "High" is a relative term. What do you mean by high, Mr. Galvin?

J. GALVIN: Well, whenever we find the castings are brittle.

MAJOR R. A. BULL: What is the high phosphorus content that makes an engine frame dangerously brittle?

J. GALVIN: I can't answer that, but I know when the phosphorus is around .08 per cent or .09 per cent phosphorus, we find the heads and gates break off very easily.

MAJOR R. A. BULL: Well, you gentlemen are being limited to considerably below .08 per cent phosphorus now in commercial specifications.

J. GALVIN: Your question is to find out, then, at what point it is dangerous?

MAJOR R. A. BULL: It is the sole purpose of this Joint Committee to determine the safe limit, and to eliminate uncertainty and guesswork. They are trying to find out the truth, and they have found out a lot of very important truths on the subject of sulphur.

C. S. KOCH: The idea in forming the Joint Committee was to settle the discussion between consumers and producers. That got so strong that seven or eight years ago they decided to investigate sulphur and phosphorus, on eight different products, wasn't it, Major Bull?

MAJOR R. A. BULL: I think it was eight originally; some of them have been excluded.

C. S. KOCH: Now, perhaps they all knew that extreme limits were dangerous, but there was discussion between .06 per cent and .05 per cent sulphur and .06 per cent and .05 per cent phosphorus, and the idea was to conduct this investigation and go forward. I understand in all the other steel products, including structural steel, they have ascertained the effects of both phosphorus and sulphur. Is that correct?

MAJOR R. A. BULL: They haven't touched phosphorus as yet.

C. S. Koch: They have worked on sulphur, then. But the steel foundry people did not go along on sulphur. Is that it?

Major R. A. Bull: That is true.

C. S. Koch: What are they going to do in phosphorus on these other products? Are they going to test boiler plate as boiler plate, or are they going to test the coupon?

Major R. A. Bull: All the tests that have been made so far have been on coupons. I don't mean simply tensile test coupons, but test specimens of various kinds, through all the ranges of tests that are known to be or believed to be reliable, and, of course, including chemical analyses and microscopic tests. The products as a whole have not been tested, and I know of no suggestion that has ever been made or is now under consideration by the committee to test entire products except castings. I am only anticipating now the probability that the Test Committee might want to consider the subject of entire castings. They formerly considered testing entire castings for the influence of sulphur.

C. S. Koch: Well, what is the particular difference between testing a coupon for rivet steel or structural steel and testing a coupon for castings?

Major R. A. Bull: They took specimens from the objects as rolled or forged. Of course, that material was all hot worked. The composition of these mill steels differs in many cases very radically from that characterizing the ordinary steel casting.

C. S. Koch: Mr. Chairman, I would like to agree with Mr. Galvin, but I don't think I can. I think the facts should have been determined long ago, to settle the discussion that has prevailed all these years with regard to sulphur. The same thing applies to phosphorus. I don't believe the problem is solved by finding some brittle castings and then sort of tracing that down. If it happens that our phosphorus is high, that is blamed. But what is the cause when our phosphorus is not high? I think the problem ought to be attacked scientifically, and that the steel founders of the United States ought to back this investigation, if made on coupons, not if made on entire castings. I think we should support Major Bull, and that the expense should not be assessed against associations like the A. F. A. and the Steel Founders' Society, and I believe that enough money can be obtained from steel foundrymen to take care of the sum which Major Bull mentioned. I don't believe we should stop now that we have gone this far. In years gone by we all have hoped that some day the matter of sulphur and phosphorus would be at least to some extent settled and not be so terribly vague as it has been.

Major R. A. Bull: May I make it perfectly plain that I haven't advocated before the Joint Committee anything that I thought ought to be

done about these phosphorus tests. I have my personal opinion, which I have tried to express, and I want you now to express your opinion, so that I can finally go before the committee conveying the opinion of the organization.

J. H. HALL: Mr. Chairman, I also sat on that Joint Committee as a representative of the National Research Council, but, being a foundryman, I am very much interested in this subject of the tests of cast steel. I don't want any of you to get the idea that these tests on forgings are being made on material which doesn't represent the full-sized forging. They are now engaged in cutting longitudinal and transverse tests from eight-inch forged bars. If those tests don't tell you something about the properties of the eight-inch forged bar as a whole, why, you just ought to see some of the transverse results they are getting. We are going to get, as steel foundrymen, a good deal of benefit out of the money that the people are putting up to have those eight-inch rolled bars tested. And, believe me, it is an expensive investigation.

Now, on this matter of sulphur, the Committee on Tests of this Joint Committee proposed to make tests on coupons cut from the castings, and in addition to make destruction tests on castings of various sulphur contents. Any foundryman knows that there are too many variables aside from sulphur to make the tests on full-sized castings as integers worth two cents. But I felt personally that the steel foundrymen made a mistake when they declined to support the program on the investigation of sulphur. The attitude taken was that we were willing to admit that the results, for instance, on sulphur in .25 per cent carbon rolled steel would be true for the cold properties of .25 per cent carbon cast steel, and I personally am very far from endorsing that attitude, but I was alone. I don't believe that an investigation would have disclosed the same relative effect of sulphur in cast steel as in rolled steel, especially when you consider the transverse tests. I think if we had supported that investigation we would have gotten some good data on the fact that with sulphur up around .08 per cent cast steel didn't lose ductility as fast as transverse tests of rolled steel.

Now, in regard to whether the tests should be made on coupons or on tests cut out of castings, after we have eliminated the question of full-scale tests on the castings, where shall we cut our tensiles? From coupons or from castings? And we all said, "Let's cut them from coupons."

Now, on sulphur, we admitted, we said that when we got up high in sulphur we were going to encounter red shortness and a lot of cracks, but the tests on rivets didn't show anything of the kind. The hot flattening tests on rivets showed perfectly good hot properties, they rolled all right and they flattened all right all the way up to .18 per cent sulphur. And when we went out and acknowledged the point and said we were willing to admit that around .08 per cent we were going to have a lot of trouble with hot cracks, we admitted more than we needed to.

When it comes to phosphorus, it is very true, as Mr. Galvin says, we know in a general way that cast steel in the cold is made brittle by too much phosphorus, but there are now results in existence that make it, in my opinion, absolutely certain that the prevailing ideas of engineers who are drawing specifications as to how high the phosphorus may be are entirely erroneous. I do not feel that it is wise for us to sit back again and say that we can allow conclusions to be drawn for cast steel from the rolled steel or the forged steel results. Sulphur and phosphorus are going to show, without a doubt, more effect in reducing the ductility of transverse tests of forgings than they do on castings, and when all these transverse tests are being made, if we pass up the opportunity to compare cast steel with transverse tests of forgings, which are important in the service of those forgings, we are missing a trick.

MAJOR R. A. BULL: I know one concern that has what I believe to be excellent steel practice and forging practice, whose engineer has told me that it is very common to get about half the reduction of area in a test specimen cut crosswise as compared with one cut lengthwise in a forging. I know of nothing like such a dissimilarity in the results of tests from the cope and the drag side of a casting.

CHAIRMAN A. H. JAMESON: Is there any further discussion? Major Bull, do I take it that you wish an expression by vote here, which then can be taken to the Directors of the American Foundrymen's Association?

MAJOR R. A. BULL: Yes, Mr. Chairman, I would like to have a vote taken, but I don't want to see a vote taken which is more or less of indifferent significance, because if an affirmative vote on this question is recorded, in the absence of any other information, I will construe it as a desire of the Association to have these tests conducted, and as an assurance, at least by the men who are present, that the investigation will be financially supported, as the result of a call for funds of reasonable amount requested from the industry for this specific purpose. Now, I just want to say one word more about the commercial significance of this thing so far as castings are concerned.

I am on several Testing Society committees that have to do with the preparation and modification of specifications. Mr. Jameson and Mr. Hall are members of most of these committees, if not all of them. They can back up my statement that there is a very strong disposition on the part of important consuming interests to increasingly lower the maximum content, both of phosphorus and sulphur, in commercial specifications for steel castings, as well as to impose definite rejection limits for carbon, manganese and silicon, one or all of them. We cannot tell what may happen in the future unless we are as diligently on the job as are those representing what we might term the opposition. I concede to these gentlemen sincerity of purpose, but we can't hope to dispel our own ignorance or the ignorance of these men unless we ascertain the facts

in a scientific manner and give them wide publicity. I don't know of any other medium through which that might be done, so far as the influence of phosphorus is concerned, than through this Joint Committee, which is composed of about 14 nationally known organizations, including all who have directly or indirectly to do with the manufacture or the use of the product.

W. J. NUGENT: Mr. Chairman, I move that it be the sense of this meeting that we support these proposed tests on phosphorus, providing the tests are confined to coupons.

C. S. KOCH: I second that motion.

CHAIRMAN A. H. JAMESON: The motion is made and seconded that it is the sense of this meeting that we support the program of the Joint Committee on the Investigation of Phosphorus and Sulphur in Steel for the investigation of the effect of phosphorus in steel castings, provided the investigation is confined to coupons.

Is there any further discussion on the motion?

MAJOR R. A. BULL: Mr. Chairman, before that vote is announced, I would like to ask Mr. Galvin if our discussion has cleared up in his own mind any obscure point, and if he now is disposed to look at the matter differently.

J. GALVIN: Well, I think it would be wise to go ahead with the investigation, in view of the statements that you gentlemen have made of the attitude of the other members of the committee.

CHAIRMAN A. H. JAMESON: If there is no further discussion, those in favor will please signify by saying "Aye." Opposed. It is carried unanimously. This will go, as the Chair understands it now, to the Directors of the American Foundrymen's Association as our recommendation.

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